













# CHEMICAL ESSAYS

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# CONTENTS.

## ESSAY

- I. Of *Bitumens and Charcoal*. Page **1**
- II. Of the Quantity of *Water* evaporated from the Surface of the Earth in hot Weather. **51**
- III. Of *Water* dissolved in Air. **75**
- IV. Of Cold produced during the Evaporation of *Water*, and the Solution of Salts. **119**
- V. Of the Degrees of Heat in which *Water* begins to part with its Air, and in which it boils. **143**
- VI. Of *Water* in a solid State; of the Heat of Spring *Water*; and of a probable Cause of the Impregnation of sulphureous Waters. **171**
- VII. Of

# C O N T E N T S.

## ESSAY

- VII. *Of Derbyshire Lead Ore.* 207  
VIII. *Of the smelting of Lead Ore, as  
practised in Derbyshire.* 251  
IX. *Of Silver extracted from Lead.* 301  
X. *Of Red and White Lead.* 337

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ESSAY I.

OF BITUMENS AND CHARCOAL.

THE analyses of pitcoal and of different woods, mentioned in the last Essay, may serve as instances of the products obtainable by distillation from bituminous and vegetable substances in general. They all of them yield water impregnated with an acid, and often also with a volatile alkaline salt, air, oils of different colours, weights, and consistencies, and a black coaly residuum. The bitumens generally taken notice



of by writers, on Natural History are, with respect to their consistence, either as fluid as oil, or as thick and tenacious as tar, or quite solid. The fluid bitumens are two, *Naptha*, and *Petroleum*, or rock-oil. These are oils which differ from each other in colour and consistence, and some other properties; the *naptha* is pale, light, and very inflammable; the *petroleum* is yellow, brown, or blackish, heavier and less inflammable than *naptha*; its difference from *naptha* is attributed to its containing a greater quantity of acid in its composition. Both these oils are found in many parts of the globe, either floating on spring water, or dripping from the crevices of rocks. *Mineral pitch* is a bitumen which differs from *petroleum* in being thicker, heavier,

and more glutinous ; it was formerly found in the environs of Babylon, and constituted, according to Vitruvius, when mixed with lime, the cement which was used in building the walls of that city. At present it is met with in several parts of Europe, and in America, where it drips from rocks, and is called by us *Barbadoes tar* : it has a very offensive smell, and great tenacity, and is called by the inhabitants of Auvergne, in France, where it exudes from the earth, and sticks to the feet, devils dung. The *Asphaltum*, or *Jews pitch*, is a bitumen much resembling mineral pitch ; it is thrown up in a liquid form from the bottom of the lake where Sodom and Gomorrah stood, otherwise called the *Dead Sea*, or the lake *Asphaltus*, from a Greek word

denoting a bitumen. This lake in the time of Esdras yielded Bitumen—*remember what I did to Sodom and Gomorrah, whose land lieth in clods of pitch\**. The bitumen floating upon the surface of the salt water, is condensed by the heat of the sun into a solid form, and is gathered by the Arabs on the shore where it is thrown. It is said to be the same substance which the Egyptians used in embalming their mummies, and it was called by them *mumia mineralis*.† This bitumen has been found in many places of Asia and Europe, as well as on the shores of the Dead Sea; all that we meet with in the shops, is either an artificial composition, or an European asphaltum, the Eastern ones being seldom brought into Europe, but  
used

\* Esd. B. 2. c. 2.

† Hasselquist's Voy. p. 285.

used by the natives either as pitch for their ships, or as an ingredient in varnishing, or dying wool.

There is a very curious experiment which illustrates the relation which these four bitumens bear to each other. The most transparent oil of turpentine, resembling naphtha, may be changed into an oil resembling petroleum, by mixing it with a small portion of the acid of vitriol; with a larger proportion of the acid, the mixture becomes black and tenacious, like Barbadoes tar; and the proportions of the ingredients may be so adjusted, that the mixture will acquire a solid consistence, like asphaltum. This experiment teaches us to conclude that naphtha, petroleum, Barbadoes tar, and asphaltum, differ chiefly from

each other, with respect to the quantity of acid which enters into their composition; and the substances procured by distilling pitcoal, or resinous vegetables, may furnish no improbable conjecture concerning the origin of these bitumens.

Let us suppose then a subterraneous fire to be situated in or near a stratum of pitcoal, of turf, of fossil wood, or of any other such bituminous matter; it is manifest that the inflammable air, and the different kinds of oils, which were collected by distilling small portions of these substances, would be elevated by the heat into the crevices of the superincumbent strata; the light and pale oil would be a sort of naptha, or petroleum, the black and tenacious oil would be a Barbadoes tar,  
and

and this might be so dried by the heat as to become an asphaltum. The oils not being miscible with water, would be found floating upon its surface, as it issued out of the bowels of the earth, and being very inflammable, might constitute burning wells, such as have been met with near Wigan, at Brosely, and in many other places : or where the oil did not meet with water, or was too heavy to float on it, we may conceive that it would impregnate the porous strata of several kinds of stones and earth. It has been observed in another place,\* that they formerly obtained a sort of tar, from a stone at Brosely ; and the stratum, which is called *shale* in Derbyshire, is so strongly impregnated with oil, that it will burn

of itself, when set on fire: the workmen in digging through the black stone, which is incumbent on the shale, sometimes meet with cavities containing a thick black oil, which has oozed out of the surrounding stone. One of the greatest *foughs*, or subterraneous passages, which has, perhaps, ever been formed in Great Britain, is that which is called Hell-car fough, in Derbyshire; this fough is driven through a stratum of shale, and the workmen are much troubled with inflammable air, which generally breaks into the fough, through the same crannies which give passage to little streams of water: they secure themselves from the air, by keeping great fans constantly in motion; for the inflammable air, being lighter than common air, floats near the roof-

of

of the fough, and being drawn down from thence, and mixed with the common air by the motion of the fans, it is circulated in the fough without danger. I am sensible that inflammable air may be produced by various other ways, as well as by the application of heat, to bituminous strata; but as bitumens do yield inflammable air by distillation, it is probable enough, that such as is met with in bituminous strata, may sometimes, at least, be referred to the action of a fire, situated, perhaps, at too great a distance from the surface of the earth, to produce any other sensible effect.

In the Duchy of *Modena* in Italy, there is a remarkable rock, which confirms very much the notion of oils and pitchy substances being separated



parated from bitumens by a kind of subterraneous distillation. The inhabitants of the district, by piercing the sides of this rock, at different distances from its summit, obtain oils of different natures, thickening and growing heavier and deeper coloured, as the canals through which they flow approach to the surface of the earth ; at the distance of a few feet below the surface, they find a very thick oil, which in digging deeper becomes soft as butter, and at still a greater depth, it is found to be as solid as pitch.

Besides *pitcoal* and *asphaltum*, there are three other solid bitumens which deserve to be mentioned—*Jet*—*Amber*—*Ambergris*. Jet so much resembles cannel-coal in its colour, in its hardness, in its receiving a  
polish,

polish, in its not soiling the fingers when rubbed upon it, and in other properties, that many authors confound the two substances together; and indeed they agree in so many qualities that it is somewhat difficult to say in what they disagree. Jet, however, when warmed by friction, has the property of attracting bits of straw, feathers, and other light bodies; but I never observed this property in any of the cannel-coals which I have tried. This property, if it may be generally relied on, as appertaining to jet, and not to cannel-coal, is a very easy characteristic, by which these substances may be distinguished from each other. Jet is said to be found only in small detached pieces, and that it is thereby distinguishable from cannel-coal, which

which is found in large beds. Some think that the woody fibrous tissue of jet, may serve to distinguish it from cannel-coal, but whoever examines large quantities of this kind of coal, will see many pieces which much resemble wood in texture. The weight of a cubic foot of cannel-coal is 1273 ounces; a cubic foot of jet is said by one author to weigh 1238,\* by another 1185 ounces †

The natural history of *Amber* is very obscure. This bitumen was for a long time thought to be restricted to the coasts of Prussia, on the Baltic Sea. It was supposed to owe its origin to the exudations of certain trees on the coast of Sweden, which falling into the sea, were there hardened by the continual action of  
 I the

\* Martin. † Lewis, Newm. Chem.

the salts, and thence carried by particular winds to the open coasts of Prussia. This opinion was supported by, and formed to account for, the ants, flies, spiders, leaves of trees, and other terrestrial matters, which are almost always found inclosed in pieces of amber, and which no doubt must be admitted, as proving its being originally in a fluid state. In Prussia they not only gather amber on the sea coast, but they frequently find it at the depth of eight or ten feet beneath the surface of the earth, but at no great distance from the sea. The superincumbent strata are sand, clay, fossil-wood, pyrites, sand again, in which the amber is found, sometimes in detached pieces, sometimes in little heaps. This distribution of the strata, where amber is found, together

gether with their proximity to the sea, has made it with some degree of probability be imagined, that this mineral owed its situation to the inundation and recession of the sea, and that it was derived partly from an oil arising from the decomposition of vegetables by subterraneous fires, and partly from a mineral acid. Amber is frequently found in Italy, where they have no fossil-wood, but great plenty of petroleum.

The natural history of *Ambergris* is as uncertain as that of amber, unless we admit the description which has been lately given of its origin, as the true one. We are told that ambergris is a part of the *Cachalot* or *Spermaceti-robate*. "It is found in this animal, in the place where the feminal vessels are usually situated in other animals.

It

It is found in a bag of three or four feet long, in round lumps, from one to twenty pounds weight, floating in a fluid rather thinner than oil, and of a yellowish colour. There are never seen more than four at a time in one of these bags ; and that which weighed twenty pounds, and which was the largest ever seen, was found single. These balls of ambergris are not found in all fishes of this kind, but chiefly in the oldest and strongest.\*” This account seems probable enough, for ambergris is a fine perfume, and we know that other perfumes, such as civet, musk, and castor, are situated in the inguinal regions of the civet cat, the musk animal and the beaver.

All vegetable, and bituminous,  
and

\* Goldsmith's Nat. Hist. Vol. VI. p. 220.

and indeed all animal substances, leave, after their volatile principles have been separated by distillation, a black coal. These coals differ somewhat from each other, with respect to their proneness to catch fire, and their ability to support it, but I will content myself with examining the nature of the residue, from the distillation of wood.

This residue does not differ from what is generally called charcoal; the slightest attention to the manner of obtaining this residue, and of making charcoal, will convince us, that no difference ought to be expected. When the wood is distilled, its communication with the external air is obstructed, its volatile parts are elevated from it, by the heat to which it is exposed, and the residue is that  
part

part of the wood which remains after all the volatile parts are driven off. In making charcoal they construct a pile of wood upon the surface of the ground, they cover the pile with a coating of turf, or other substances, and make the coating so compact, that it will not admit of air, except through some little round holes, which are purposely made in it, and which can be stopped at pleasure. When the pile, thus constructed, is set on fire, part of the oil of the wood is consumed during the burning of the pile, the other part, together with the air and water contained in the wood, is evaporated, and there remains, when the operation is finished, the earthy part of the wood, called in that state charcoal. Thus the making of charcoal



is a kind of distillation, for the coating which surrounds the pile of wood, may be compared to a retort.

Henckel informs us, that 150lbs. of oak, will produce 62lbs. of charcoal\*; but he does not inform us whether the oak was dry or green, whether it had its bark on or was peeled, whether it was all heart of oak, or partly heart, and partly sap, whether the operation of making the charcoal was discontinued as soon as the wood ceased to smoke, or protracted some time longer; and yet a difference in any one of these circumstances, will sensibly influence the weight of the charcoal, procurable from a definite weight of wood.

The woods which I converted into charcoal were dry, and had been fel-

1

led

\* For. Satur. c. iv. p. 55.

led many years ; their relative weights were taken with great exactness.

Weight of a cubic foot of

|          |   |      |                |
|----------|---|------|----------------|
| Water    | — | 1000 | avoir. ounces. |
| Box      | — | 950  | —              |
| Oak      | — | 892  | —              |
| Ash      | — | 832  | —              |
| Mahogany | — | 816  | —              |
| Walnut   | — | 790  | —              |
| Deal     | — | 615  | —              |

Authors differ very much as to the weights which they have assigned to definite bulks of the same kind of wood. Thus, one estimates the weight of a cubic foot of dry box at 1030<sup>\*</sup>; another at 1201 ounces†: one puts the weight of a cubic foot of dry oak at 925‡; another at 800 ounces§. To the more obvious

B 2

Sources

\* Cotes Hydros. p 73.    † Ferguson's  
Tab. p. 237.    ‡ Cotes.    § Emerson's Mech.  
p. 132.

sources of this diversity, in the weights of equal bulks of the same kind of wood,—such as the wood being green or dry, being cut from the boll or branch of a tree,—one may be added, which has not, I believe, been sufficiently attended to—I mean the great loss of weight which in certain circumstances, the same piece of wood sustains, by a simple exposure to the atmosphere, in the course of a few days.

From the middle of a branch of an oak tree, which had been felled in April, and exposed without its bark, to the hot summer of 1779, I cut Sept. 4, a round piece, about six inches in diameter, and three in thickness: Sept. 15, I cut from the heart of this piece of oak a small slip, 3 inches in length,  $\frac{1}{4}$  of an inch in thick-

thickness, and 79 grains in weight; at the same time, I cut a similar slip from the sap of the same piece, the weight of which also was 79 grains: these two pieces were put into the drawer of my study table, and being weighed again, Sept. 25, the heart of oak had lost 8 grains, or near  $\frac{1}{10}$  of its weight; the sap had lost 12 grains, or above  $\frac{1}{7}$  of its weight. Now if the weights of several equal bulks of these woods had been taken on the 15th, and on the 25th of September, it is obvious (notwithstanding the contraction they might have suffered) that there would have been some difference in them, though the woods themselves appeared equally dry on both days.

This speedy diminution of weight which wood undergoes by exposure

to the air, being a matter of some importance in an œconomical view, I will mention another experiment which I made on the subject. A piece of Ash cut March 17, 1780, from the middle of a large tree, which had been felled six weeks before, was accurately weighed; its weight was 317 grains, its length 3 inches, and its breadth 2. It was weighed again March 24, it had lost in the course of 7 days 62 grains, or near  $\frac{1}{5}$  of its weight. I weighed this same piece of wood on the 25th of August in the same year, but it had not lost any thing of its weight, from the 24th of March to the 25th of August. The two pieces of oak, mentioned in the last experiment, were weighed also, on the 25th of August, 1780; they had neither of

them

them lost, in the course of eleven months, quite 1 grain; hence it appears, that the matter which is dispersed from wood after it is cut, is soon evaporated: this matter probably consists chiefly of water. The carriage of wood, especially by land, is very expensive: if an oak or an ash tree was cut into boards, or scantlings, upon the spot where it is felled, there would be a saving of the carriage of one ton in six or seven from the evaporation of the substance of the wood; to say nothing of chips and other refuse parts.

It is well known that all wood becomes heavier than water, by having the air extracted from the pores, either by an air-pump, or by boiling it in water. The woods of which I have given the relative weights,

were all of them rendered heavier than water, by a long continuance in cold water; for the heat of the water in which they were put, never exceeded 60 degrees. They sunk in the water after they had been soaked in it for different lengths of time, but it required above 100 days soaking before the deal would sink. After they had all lain in water for 110 days, I took them out, and let them dry by the gradual heat of the atmosphere for above a month; I then weighed them, and found that box, oak, and ash, had each of them lost  $\frac{1}{32}$  of the weight they had before they were put into the water; but that mahogany, walnut, and deal, had lost only  $\frac{1}{60}$  of their weight. This loss of weight is occasioned, partly by the escape of some portion  
of

of air, and partly by a dissolution of some of the other principles of the woods; for the water, in which they were placed, had evidently acted upon them, its colour and consistence being both changed. Most woods contain both a *gummy* and a *resinous* part; and gums being soluble, and resins not soluble in water, we can have no difficulty in apprehending the reason, why some sorts of wood lose a greater proportion of their weight, by being immersed in water, and afterwards dried, than others. Since the same piece of wood has very different weights, when dry and when soaked with water; the covering carts, ploughs, and other husbandry gear, usually made of ash, with a coarse kind of paint which will keep out the rain,

is



is a practice full as serviceable in lessening the weight of the implement which is to be moved by the strength of a man or a horse, as in preserving the wood of which it is made from decay.

I took square pieces of the woods before mentioned, each piece being 3 inches in length, and weighing exactly 96 grains, and exposed them, when covered with sand, in a crucible, to the action of the same fire, which was strong enough to keep the crucible red hot, for three hours; they were at the end of that time, all of them converted into perfect charcoals; the weights of the respective charcoals were taken, whilst they were still *warm*, from the operation, and are expressed in the following table :

Walnut

|          |    |      |      |    |                   |
|----------|----|------|------|----|-------------------|
| Walnut   | 96 | grs. | gave | 25 | grs. of charcoal. |
| Oak      | —  | 96   | — —  | 22 | —                 |
| Box      | —  | 96   | — —  | 20 | —                 |
| Mahogany | 96 | — —  | 20   | —  |                   |
| Ash      | —  | 96   | — —  | 17 | —                 |
| Deal     | —  | 96   | — —  | 15 | —                 |

There is a good reason for remarking, that the charcoals were weighed whilst they were warm, for in weighing them a few days afterwards, I found that they had all increased in weight in consequence of *something* which they had attracted from the atmosphere: their weights then were —walnut ~~26~~—oak 24—box 23—mahogany 24—ash 18—deal 16—grains.

The quantities of residue remaining from the distillation of 96 ounces of oak, box, and mahogany, were respectively 30,  $26\frac{1}{2}$ , and  $27\frac{1}{2}$  ounces,

ounces, which numbers are severally larger than those, expressing the quantities of charcoal obtainable from 96 parts of those woods; this difference may proceed from the woods, employed in the two processes, being of different qualities, or, more probably, from the heat in which the charcoal was made, being greater than that employed in the distillation; for the stronger the fire, the less is the quantity of charcoal, which a definite weight of wood will yield.

In making charcoal the workmen observe, that the pile of wood is sensibly diminished in size by the operation; this proceeds from the shrinking of the wood. All the kinds of wood which I charred were diminished in all their dimensions,

the.

the mahogany, oak, and walnut, were the least diminished; and the box was the most diminished; I thought it had lost an eighth part of its length. This diminution not only depends upon the nature of the wood, but it is influenced by the strength and continuance of the heat, that being most diminished, which has sustained the greatest heat.

Though charcoal, from every sort of wood, is incapable of being decomposed, by the strongest fires in close vessels, yet it is a compounded body, and may be decomposed by being burned in the open air.

Van Helmont says, that 62 pounds of oak charcoal will, by burning, yield only 1 lb. of white ashes. The other 61 pounds which are dispersed into the air, he considers as a vapour  
of

of an elastic nature, which can neither be collected in vessels, nor reduced into a visible form. This vapour he called by a new name, *gas*\*.

Stahl is of opinion, that 10 lbs. of charcoal made from porous woods, such as fir and fallow, will not when burned with a very slow fire, yield above 1 lb. of ashes†; this quantity however, it must be remarked, is above six times the quantity assigned by Van Helmont to oak which probably contains more ashes in a definitive weight of charcoal, than either fir or fallow.

Geoffroy,

\* Hunc Spiritum, incognitum hactenus, novo nomine gas, voco, qui nec vasis cogi nec in corpus visibile reduci potest. Van Hel. Op. omn. p. 193. Some derive gas from the Dutch ghaast-spirit; others from the German gascht, a frothy ebullition.

† Stahlia Exper. Numero CCC. p. 17.

Geoffroy, from somewhat less than 34 ounces of the charcoal, remaining after the distillation of the heart of guaiacum, got near three ounces of white ashes, by calcining the coal in an open fire for 12 hours. From near  $23\frac{1}{2}$  ounces of the coal, remaining from the distillation of the sap of guaiacum, he got near  $1\frac{1}{2}$  ounce of ashes. And  $29\frac{1}{2}$  ounces of the coal, from the bark of guaiacum, gave him  $13\frac{1}{2}$  ounces of white ashes\*.

Lastly, Mr. Sage assures us that 100 pounds of charcoal will not, when burned, furnish quite 2 ounces of ashes†.

These accounts, it must be acknowledged—

\* Geoff. Mat. Med. or treatise on foreign vegeta. by Thicknes, p. 112.

† Exper. sur. l' Alk, Vol. fluor. p. 27.

known, differ very much, as to the quantity of ashes obtainable from a definite weight of charcoal; and the difference, I think, is much greater than what can wholly be attributed to the different textures of the several woods; a part of this diversity may, probably, arise from a difference in the manner of burning the charcoal. When charcoal is burned in small quantities, and in a slow fire, less of its substance will be dispersed into the air, than when the quantity is larger, and the stream of air which supports the fire, is more rapid. This seems not improbable; but if the weight of the ashes remaining from the burning of a definite weight of charcoal, be at all influenced by the degree of fire, it seems reasonable to suppose, that what

what is driven off by the violence of the fire, is of the same earthy nature as that which remains when the fire is more moderate ; at least it may be argued, that when charcoal is burned with a slow fire, some of its principles, its oily principle for instance, though it, probably, also contains a saline one, are more completely decomposed, than when it is consumed with a violent fire, and that the decomposition of these principles gives an additional quantity of earth or salt to the ashes.

If there be any truth in this notion, we must not say, that the 61 pounds of matter which, according to Van Helmont, are dispersed into the air from 62 pounds of charcoal, are wholly of an elastic nature ; since they may consist principally of an



attenuated earth, which being driven off by the current of air, requisite for the maintenance of the fire, remains for a time suspended in the atmospherical air, without being in its own nature elastic. I would not be understood to say, that the whole of what is dissipated, during the burning of the charcoal, is an attenuated earth, since it is certain, that the earth of the ashes is not inflammable, and that charcoal contains something which is inflammable: it is allowed also, that simple earth is inodorous: and it is well known that charcoal, during its inflammation, disperses something into the air, which has a strong smell; this *something* by which charcoal is rendered inflammable, and by which the air is infected with a particular smell, during the burning

ing of the charcoal, is called by most chemists the phlogiston\*. This

c 2 phlogiston,

\* Phlogiston is a constituent part of metallic substances, and it seems, when separated from them, to be of an elastic nature. I distilled zinc with *strong* acid of vitriol, and obtained a portion of sulphur, produced as it should seem, by the acid's uniting itself with the phlogiston of the zinc. No inflammable vapour was produced, till the sulphur began to be sublimed; then, indeed, there escaped a vapour, composed, I think, of the attenuated parts of sulphur, which upon the approach of a candle took fire. Another portion of zinc was distilled with *weak* acid of vitriol; before the zinc felt the heat of the fire, the inflammable air, separable from zinc by a weak acid of vitriol, passed into the receiver, and being set on fire, burst it with a great explosion: another receiver was applied, and the distillation continued to dryness, but not a particle of sulphur was produced, the phlogiston necessary for its formation having, probably, been separated from the zinc, by the violent action of the

phlogiston, whether it be an elastic inflammable fluid, or an unelastic earth of a particular kind, constitutes, probably, but a very small portion of the weight of what is dispersed into the air, from burning charcoal : we all know what a strong smell may be diffused through a large room, from the ignited snuff of a candle, or from a very small piece of charcoal, which has not been thoroughly burned; the vapours issuing from these substances are of an oily saline nature, and are visible : the vapour of charcoal, though it is too subtle to be seen, may be of a nature somewhat similar, and capable

acid, and consumed at once by the inflammation. May it not, from the comparison of these experiments, be conjectured, that the phlogiston of metals is an elastic inflamma-

ble of a very extensive diffusion through the air. An infant has been known suddenly to expire, from the smoke of a candle blown out under its nose, and the vapour of charcoal is most dangerous, when the charcoal has not been thoroughly burnt.

It has been found by experiment, that the common atmospherical air is much altered in its properties, by being made to pass through red hot charcoal, into the vacuum of an air-pump; it then extinguishes the flame of a candle, and animals die in it\*. A similar change takes place, when charcoal is consumed in an apartment, which has not a sufficient supply of fresh air; the instances of persons who have unhappily lost their lives in such air, are very common in

all countries, where much use is made of charcoal; but especially in Russia, where their apartments are heated by ovens, containing red hot charcoal\*. The change which the atmospherical air undergoes, from the burning of charcoal, may proceed either from the air, having lost some of its constituent parts in coming in contact with the burning charcoal, or from its having gained something from the charcoal, or from its having done both at the same time; just as water, which passes through a lump of salt or sugar, loses

a great

\* Philos. Transf. 1779, p. 325—Where there is mention made of the Russian method of recovering persons who have been rendered senseless by the vapour of the charcoal; it consists in carrying the person into the open air, rubbing him with snow or cold water, and pouring water or milk down his throat.

a great part of the air it contains in its natural state, and gains a portion of the salt, which becomes dissolved in it, and upon both accounts suffers a change of its properties.

It is generally admitted, that charcoal and all other bodies, nitrous ones excepted, cease to burn, as soon as they cease to be supplied with fresh air, and the air has, chiefly on this account, been thought to communicate something to the fire, by which the fire was maintained, and the air was consumed. And this opinion has been confirmed by observing, that a definite quantity of air was much diminished in bulk by bodies being burned in it. Thus, if 10 cubic inches of air be made to pass through red hot charcoal, they will be reduced to nine, and there-

are means of making the diminution still greater.

Dr. Hooke advances another hypothesis ; he allows air to be necessary to the support of fire, but he thinks that it contributes to this support, not by imparting any thing of its own substance to the fire, but by *dissolving* the inflammable principle of bodies, as water dissolves salts \* : according to the former hypothesis, air is the *food* ; according to this, it is the *receptacle* or *solvent* of fire.

Dr. Priestley, to whose inventive genius and indefatigable industry the  
philos-

\* Hooke's Micogr. p. 103. and Posthum. Works, p. 169. Juncker seems to have entertained a similar notion—*ingens aeris quantitas requiritur ad dissolvendas et recipiendas ignitas illas et ultimo motu attenuatas particulas, unde nisi sat aeris sit extinguitur ignis.* Junck. Conf. Chem. Vol. I. p: 157.

philosophic world is peculiarly indebted for his inquiries into the nature of fictitious airs, has observed, that common air is diminished one fifth by the fumes of burning charcoal; and this diminution, he thinks, is some how or other effected by the air being highly charged with the phlogiston of the charcoal; and he observes, which agrees very well with Dr. Hooke's hypothesis, that when any definite quantity of air is fully saturated with phlogiston from charcoal, no heat that he had ever applied was able to produce any more effect upon the charcoal\*.

Though common air is diminished in bulk by the fumes of burning charcoal, and of other bodies in a state of combustion, yet a bottle or a bladder

\* *Philos. Trans.* 1772, p. 225—230.



filled with this diminished air, weighs less than when it is filled with common air\*, in the proportion of 183 to 185. That 5 cubic inches of common air should be reduced by the fumes of burning charcoal to 4 cubic inches, and that these 4 cubic inches of infected air should weigh less than 4 cubic inches of common air, cannot well be accounted for without admitting, that a part of the 5 cubic inches of atmospheric air has been, by some means or other, taken away, at the same time that its bulk was reduced to 4 cubic inches.

Being desirous of seeing, whether the property I had observed in charcoal, with respect to its weighing less when it was quite cold, than when it was warm from the fire in which it

\* Priest. Exp. and Ob. Vol. II. p. 94.

it had been made, was a general property appertaining to all hot and cold charcoal, I weighed several pieces when they were cold, and again, when they were so hot as to be handled with difficulty, and found that they all lost (they were of the same kind of wood) about 1 part in 12 of their weight, and that being left to cool in the open air, they regained what they had lost in a few days. This acquisition of weight was made most rapidly at first: a piece which weighed 240 grains when cold, was reduced by being heated, to 220 grains, and being left to cool, it gained 9 grains in 4 hours, and 15 grains in 8 hours. From the manner in which charcoal is made, it is probable that what remains adherent to the wood, is not greatly different

different from what is forced from it by the last degree of heat; now this consists of an acid, and an oil rendered thick and pitchy by its union with an acid; may we not hence suppose, that it is a portion of fixed acid, which attracts the humidity of the air, or perhaps the air itself, when the charcoal is hot, and becomes saturated therewith, and that what was attracted is again driven off, when the charcoal is again heated; and thus the charcoal becomes again capable of exerting its attraction, and acquiring an increase of weight? It is some confirmation of this hypothesis, that charcoal, when taken out of hot sand, takes fire upon exposure to the air, and for much the same reason, probably, that Homberg's pyrophorus takes  
fire

fire in the open air\*. Guaiacum contains a stronger acid than most kinds of wood; and Geoffroy has observed, that "the coal of guaiacum being taken out of the retort, and exposed to the air, even two or three days after the process, takes fire immediately of its own accord;

pro-

\* Homberg's Pyrophorus is known to every school-boy. It is made by calcining together for a proper time, and in proper quantities, either alum or any salt containing the vitriolic acid, with honey, sugar, flour, or any animal or vegetable substance, capable of being reduced to a coal. Part of the vitriolic acid being uncombined with the phlogiston of the coal, and being in a dry condensed state, attracts the humidity of the atmosphere, and generates such a degree of heat by its mixture with water, as is sufficient to inflame the other part of the pyrophorus. Pyrophori may be made without the vitriolic acid, but some acid probably enters into their composition.

provided, that when the distillation is over, the neck of the retort be carefully stopped, and the vessels and furnace be left to cool of themselves\*."

This property of increasing in weight by exposure to the air, belongs to the hot coal of pitcoal, as well as to that of wood. I took some red hot cinders, and weighing them in that state, left them to cool; in 12 hours they had gained one 75th part in weight, and in 4 days they had gained one thirtieth of their weight. Some coak which had been burned with a strong fire, gained much less than the cinders.

It has been observed in another place, that charcoal may be decomposed, by being distilled with the  
acid

\* Treatise on Foreign Veget. p. 111.

acid of vitriol\*; this acid robs the charcoal of its inflammable principle, and reduces it to an earth: no other menstruum seems to have any action upon it. What alteration might be produced in charcoal, by quenching it when red hot, in various menstruums, or by boiling it in them, or by keeping it immersed in them, when cold, for a long time, or by other less obvious processes, it does not fall within my design to inquire.

Animals and vegetables are soon reduced by putrefaction to an earth; many sorts of stones and metallic substances are crumbled into dust by the action of air and water; but charcoal remains unchanged for ages, whether it be exposed to the air, or immersed in water, or buried in the earth. The beams of the theatre

as

\* Vol. I. p. 175.

at *Herculaneum* were converted into charcoal by the *Lava*, which overflowed that city; and during the lapse of above seventeen centuries the charcoal has remained as intire as if it had been formed but yesterday, and it will probably continue so to the end of the world. This incorruptibility, as it may be called, of charcoal, has been known in the most distant ages; for it has been observed, that the famous temple of *Ephesus* was built upon wooden piles which had been charred on the outside. The custom of charring the ends of posts, which are to be fixed in the earth, is very common; and I have often wondered that the same custom has not prevailed with respect to the wood used in mines and subterraneous drains. The tim-  
bers

bers which support, in many places, the roof of the foughs through which there is a current of water, are waisted away in a few years, that part of them especially which is exposed to the alternatives of moisture and dryness by the rising and falling of the water is soon rotted, and this part one would think would be charred with great advantage.





## ESSAY II.

OF THE QUANTITY OF WATER EVAPORATED FROM THE SURFACE OF THE EARTH IN HOT WEATHER.

**T**HERE are many operations constantly carrying on by natural means, which, though they escape the ordinary observation of our senses, sufficiently excite our astonishment, when once discovered. The vast quantity of a particular kind of air, with which the atmosphere is daily impregnated, from the combustion of all sorts of fuel, is

one instance of this kind ; and the water which is raised into the atmosphere from the surface of the earth, is another. Who would have conjectured, that an acre of ground, even after having been parched by the heat of the sun in summer, dispersed into the air above 1600 gallons of water in the space of twelve of the hottest hours of the day ? No vapour is seen to ascend, and we little suppose that in the hottest part of the day, more usually does ascend than in any other. The experiment from which I draw this conclusion, is so easy to be made, that every one may satisfy himself of the truth of it. On the 2d of June, 1779, when the sun shone bright and hot, I put a large drinking glass, with its mouth downwards, upon a grass-plot which

was

was mown close ; there had been no rain for above a month, and the grafs was become brown ; in less than two minutes the inside of the glass was clouded with a vapour, and in half an hour drops of water began to trickle down its inside, in various places. This experiment was repeated several times with the same success.

That I might accurately estimate the quantity, thus raised, in any certain portion of time, I measured the area of the mouth of the glass, and found it to be 20 square inches : there are 1296 square inches in a square yard, and 4840 square yards in a statute acre ; hence, if we can find the means of measuring the quantity of vapour raised from 20 square inches of earth, suppose in

one quarter of an hour, it will be an easy matter to calculate the quantity which would be raised with the same degree of heat, from an acre in 12 hours. The method I took to measure the quantity of vapour, was not perhaps the most accurate which might be thought of, but it was simple and easy to be practised: when the glass had stood on the grass plat one quarter of an hour, and had collected a quantity of vapour, I wiped its inside with a piece of muslin, the weight of which had been previously taken; as soon as the glass was wiped dry, the muslin was weighed again, its increase of weight shewed the quantity of vapour which had been collected. The medium increase of weight, from several experiments made on the same day,

between

between 12 and 3 o'clock, was 6 grains collected in one quarter of an hour, from 20 square inches of earth. If the reader takes the trouble to make the calculation, he will find that above 1600 gallons, reckoning 8 pints to a gallon, and estimating the weight of a pint of water at one pound avoirdupois, or 7000 grains troy weight, would be raised, at the rate here mentioned, from an acre of ground in 24 hours.

It may easily be conceived, that the quantity thus elevated will be greater when the ground has been well soaked with rain, provided the heat be the same; I did not happen to mark the heat of the ground when I made the fore-mentioned experiments; the two following are more circumstantial: the ground had been

wetted the day before I made them by a thunder shower, the heat of the earth, at the time of making them, estimated by a thermometer laid on the grass, was 96 degrees ; one experiment gave 1973 gallons from an acre in 12 hours, the other gave 1905. Another experiment made, when there had been no rain for a week, and the heat of the earth was 110 degrees, gave after the rate of 2800 gallons from an acre in 12 hours ; the earth was hotter than the air, as it was exposed to the reflection of the sun's rays from a brick wall.

The heat in *Bengal* in the summer months is variable, in the shade from 98 to 120 degrees\*, and in the sun it probably does not fall short of

140

\* *Philos. Transf.* 1767, page 218, and for the year 1775, p. 201.

140 degrees ; hence, after the earth has been well drenched by the overflowing of the *Ganges*, immense quantities of vapours must be daily raised, to the amount, perhaps, of five or six thousand gallons from an acre, in twenty-four hours. The rainy season in Bengal lasts from the beginning of June to the middle of October ; all this interval is considered as an unhealthy time, but especially the latter part of it, for then the earth begins to grow dry, the slime left upon its surface, consisting of decayed vegetables and other putrescent bodies, begins to corrupt ; and the sun, by its violent and continued action, raises up into the air not a pure water, but water impregnated with putrid particles of all kinds.

Whether a merely moist situation  
be



be unwholesome, may be much questioned ; but that moisture arising from earth or water in a state of putrefaction is so, cannot well be doubted. The overflowing of the *Nile* puts a stop to the plague in *Egypt*, infomuch, probably, as it puts a stop to the putrefaction of the canals of *Grand Cairo* and other places. Agues and putrid fevers are much more frequent in the fens of *Cambridgeshire* and *Lincolnsbire* in very dry, than in wet years ; the *Irish*, who annually come to reap the harvest in the fens of *Cambridgeshire*, have been so sensible of the difference, that for the three or four years last past, which have been very dry, they have entered upon their task with great reluctance, and apprehension of what they call the *Fen-shake* : The  
States

States of *Holland*, in the year 1748; laid the country around *Breda* under water, and ordered the water to be kept up till the winter, in order to stop a sickness which had arisen from the moist and putrid exhalations of half-drained grounds.\* The *Arabs* are said to take a horrid kind of vengeance when they think themselves injured by the *Turks* at *Bassora*; they contrive so overflow the adjoining country : a pestilential fever begins to shew itself as the land begins to grow dry by the evaporation of the water, and it rages with such violence as to carry off many thousands of the inhabitants of that city †.

The nature of the soil must have a great influence on the health of the people

\* Sir J. Pringle's *Dis. of the Army*, p. 63.

† *Philos. Trans.* 1778, p. 215.

people who inhabit it, so far as that is dependent on the moisture or dryness of the air. There is, probably, as much water raised into the air, in a hot day, from an acre of ground in the fens of *Cambridgeshire*, as is raised in two or three days from an equal surface in the sandy parts of *Norfolk* and *Suffolk*. Not but the most sandy country may have a very moist atmosphere, when water happens to be found near the surface; for the heat of the sun will penetrate through the sand, and raise the water in vapour, which will find an easier passage through the sand than it would do through a less open soil. Thus the soil in some parts of *Dutch Brabant* is a barren sand, but water is every where to be met with at the depth of two or three feet, and in  
 propor-

proportion to its distance from the surface the inhabitants are free from diseases \*.

Vegetation must be greatly influenced by the quantity of water which is raised from the earth ; some soils retain humidity much longer than others, and one great use of marles and other manures, is, to render the soil on which they are put less liable to be deprived of its moisture by the heat of summer. The water, in ascending from the bosom of the earth, moistens the roots, and in being dissolved in the air, it affords nutriment to the branches of vegetables ; but as vegetation may be injured either by a defect, or an excess of moisture, and as different plants require different quantities of it, for attaining  
their

\* Disease of the Army, p. 62.

their utmost perfection, it merits the attentive observation of the farmer to suit his plants and his manures to the nature of the soil. There are many sandy and limestone soils, which are covered almost with flints or limestone pebbles; the crop of corn would, probably, be less, if these stones were removed; for they are serviceable, not only in sheltering the first germs of the plant from cutting winds, but they impede the escape of moisture from the earth; the ascending vapour strikes upon that surface of the stone which is contiguous to the earth, and is thereby condensed, and thus its further ascent is for a time, at least, prevented.

Upon the same grass-plot, and contiguous to the glass used in the experiments, I placed a silver cup, with

with its mouth downwards, of a shape similar to that of the glass, and nearly of the same dimensions; but I could never observe that its inside had collected the least particle of vapour, though I frequently let it stand on the glass for half an hour, or more.

By means of a little bees wax, I fastened an half crown very near, but not quite contiguous, to the side of the glass, and setting the glass, with its mouth downwards, on the glass, it presently became covered with vapour, except that part of it which was near to the half crown. Not only the half crown itself was free from vapour, but it had hindered any from settling on the glass which was near it, for there was a little ring of glass surrounding the half crown.

crown to the distance of  $\frac{1}{2}$  of an inch which was quite dry, as well as that part of the glass which was immediately under the half crown; it seemed as if the silver had repelled the water to that distance. A large red wafer had the same effect as the half crown; it was neither wetted itself, nor was the ring of glass contiguous to it wetted. A circle of white paper produced the same effect, so did several other substances, which it would be tedious to enumerate.

These phenomena, respecting the different dispositions of different bodies to attract the *rising* vapour, are similar to what others have taken notice of concerning the *falling* of dew, and are, probably, to be explained upon the same principles, whatever they may be. Muschenbroek

brook placed on the leaden terrace of the Observatory at Utrecht, vessels of glass, china, varnished wood, polished brass, and pewter: he found that in the course of a night the glass, china, and varnished wood, had collected a great abundance of dew, but that not a drop had fallen on any of the polished metals\*. M. du Fay exposed to the air, when the dew was falling, two large funnels, one made of glass, the other of polished pewter; the necks of the funnels being inserted into vessels proper to retain any moisture which might be collected by them; he sometimes found in the morning that the vessel under the glass funnel contained an ounce or more of water,

VOL. III.

E

but

\* Introd. ad Philos. Nat. Tom. II. p. 990.



but he never observed so much as a drop in the other \*.

A great part of the water which is raised into the air from the perspiration of the earth during a hot day, descends down again upon its surface in the course of the night; and this is the reason that the dews are the greatest in the hottest weather, and in the hottest climates. The earth retains the heat it receives in consequence of the sun's action longer than the air does; water, moreover, is evaporable in all degrees of heat; hence water may continue to rise from the earth, when the air, being cooled by the absence of the sun, is no longer able to sustain what is thus raised, or to retain what it

\* Hist. de l'Acad. des Sciën. 1749.

it had taken up during the day time; and a dew from these different causes may, under certain circumstances, be found both to rise and fall during the whole night.

Egypt, at one season of the year, is so parched up by the heat, that the surface of the ground becomes quite rugged with fissures; at this time the dew, proceeding from the vapour exhaled from the earth, is very plentiful, and by its plenty prevents the total destruction of the country. " This dew is particularly serviceable to the trees, which would otherwise never be able to resist the heat; but with this assistance they thrive very well, blossom and ripen their fruit. Therefore the upper parts of the Egyptian trees, at one time of the year, do the office of

R 2

roots,

roots, attracting nourishment by their absorbent vessels, the leaves, from the moist air\*.

The quantity of water which was condensed on the inside of the glass, I found to be accurately proportionable to the time during which it stood on the grass; for in one experiment 6 grains were collected in 10 minutes, and in another 15 grains were collected in 25 minutes; now the proportion of 6 to 10 is the same as that of 15 to 25.

In order to see whether the copious vapour collected by the glass was owing to the natural perspiration of the grass, or to a kind of mechanical distillation from the body of the earth, I put the glass upon a foot-path which was dry, and had no  
grass

\* Hasselquist's Voy. p. 455.

grafs growing upon it, the vapour rose from the footpath as well as from the grafs, but not so abundantly.

From what has been advanced, it may, probably, be justly inferred, that the air contiguous to, or not far removed from, the surface of the earth, whether that surface be plain or mountainous, barren, or covered with vegetables, will be much more loaded with the vapour which arises constantly from the earth, than that which is at the distance of even a few yards from the surface. This point may be illustrated by the following hypothesis—Suppose the earth to be a globe of rock salt, and to be covered with water to the height of a mile; imagine the water to be divided into four spherical

E 3 . . . shells,

shells, each  $\frac{1}{4}$  of a mile in thickness. Now the first shell, which is supposed to be contiguous to the surface of the salt, would soon saturate itself with the salt, and becoming thereby heavier than the water at a greater distance, it would not, by the ordinary motion of the winds and tides, soon mix itself with the whole mass of water; but it would contain far more salt in solution than the second shell, and the second would contain more than the third, and the third more than the fourth. Let us further suppose the salt contained in the whole of the water to be precipitated, and the precipitation to begin from the shell farthest removed from the surface of the earth; it is evident, that the quantity of the precipitate will increase,

not simply with the increase of space through which it has descended, but, in a much higher proportion, inasmuch as the last shell through which it descends may be supposed to contain three or four times as much salt as the uppermost. In like manner, it seems reasonable to suppose that the air which is near the surface of the earth will be much more charged with water, which it dissolves as water dissolves salt, than that which is situated at the distance of even a few yards from the surface.

Dr. Heberden was the first person who took notice that a much larger quantity of rain falls into a rain-gage situated near the surface of the earth, than into one of the same dimensions situated a few yards above

it \*; and he thinks that this difference is to be explained from some unknown property of electricity. The fact is placed beyond controversy, by experiments which have been made at various places; at Liverpool in particular it has been observed, that “ a vessel standing on the ground in a spacious garden, received *double* the quantity of rain which fell into another vessel of equal dimensions placed near the same spot, but eighteen yards higher†.” I am far from thinking that the foregoing observations relative to the quantities of water contained  
in

\* Phil. Transf. 1769, p. 361.

† See an ingenious essay on the subject, by Dr. Percival, who has explained the phenomenon from the known principles of electricity. Essays by Dr. Percival, p. 112.

in equal bulks of air at different heights from the surface of the earth; contain a satisfactory explanation of this phenomenon; yet it may be remarked, that rain-gages placed at equal distances from the surface of the earth, collected nearly equal quantities of rain, though one of them was situated on a plain, and the other on a mountain 450 yards in height above the plain\*: this observation is some confirmation of the hypothesis which has been mentioned, as on that supposition it follows, that the air at the same distance from the surface of the earth, is equally impregnated with water, other circumstances being the same, and therefore equal quantities of rain ought to be collected by vessels placed

\* Philof. Transf. 1772; p. 294.



placed at equal distances from the surface of the earth ; though according to the same supposition, a much larger quantity *ought* to be collected by a vessel placed on the surface, than by one placed a few yards above it. Thus this hypothesis, admitting its truth (which future experiments will perhaps establish), seems as if it was sufficient for explaining the phenomenon ; I would be understood however to mention it with much diffidence, and was I as much skilled in electricity, as the very worthy and ingenious person, who first noticed the fact, is in every branch of natural philosophy, I might probably have seen reason not to mention it at all.

## E S S A Y   I I I.

### OF WATER DISSOLVED IN AIR.

**W**E have seen, in the preceding Essay, that large quantities of water are raised from the earth in the hottest weather: the water, which is thus elevated, is no more visible in the air, than a piece of sugar is visible in the water wherein it happens to be dissolved, nor is the transparency of the air injured by the water it has received from the earth;

earth; and therefore we conclude, that the water is not merely *mixed* with the air, but really *dissolved* in it; a perfect transparency of the fluid, in which any body is dissolved, being esteemed the most unequivocal mark of its solution.

The cause of the ascent, suspension, and descent of vapours, is not yet fully determined; many think that electricity is the principal agent in producing these phenomena\*; whilst others are of opinion, that water is raised and suspended in the air, much after the same manner in which salts are raised and suspended in water; and it must be owned that this  
 opinion

\* Philof. Transf. 1755, p. 124.—*Electricitas vapores in aërem extollit, in aëre suspendit, et ex aëre in tellurem depluit.* Prof. Bayers Exp. de Elec. Theo. p. 106.

opinion (which future experience may shew not to be wholly inconsistent with the other) has a great appearance of probability.

Salts, in general, are more speedily dissolved in warm water than in cold; and water, in like manner, is more speedily dissolved in warm air than in cold. We have a sensible proof of this in the exhalation of dew, it being much sooner dried up in places exposed to the direct rays of the sun, than in the shade, because the air in the shade being some degrees colder than that in the sun, is not able to dissolve the same quantity of water in the same time.

When water is saturated with any kind of salt in a definitive degree of heat, then will it retain the salt as long as it retains its heat; but if the

heat be lessened, the transparency of the solution will be destroyed, a part of the salt will become visible, and fall to the bottom, in consequence of its superior weight; what falls to the bottom will be re-dissolved, as soon as the water regains its heat. It is obvious that the quantity of the salt which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the solution is saturated, and partly on the degree of cold to which the solution is reduced. Thus water of 80 degrees when saturated with salt, contains more salt than it would do if it had only 70 degrees of heat, and in being cooled to 50 degrees, the precipitation of salt will be greater in the first instance, than in the second; though it might probably be  
the

the same if the solution of 80 degrees was cooled only to 60, and that of 70 to 50. Something very analogous to all this may be observed with respect to the solution of water in air. In misty weather we frequently see the mist of the morning intirely vanishing towards the middle of the day, and coming on again towards the evening; the reason of which seems to be, that the air being warmed by the approach of the sun to the meridian, is able to dissolve the morning mist, but as the air grows colder again towards the evening, the water which had been perfectly dissolved by the mid-day heat begins to be precipitated, the transparency of the air is destroyed, and an evening mist is formed.

This phenomenon has been observed

served to prevail, in the coldest atmosphere that has ever yet been taken notice of, on the surface of the globe; for in January 1735, when the cold in *Siberia* was equal to 157 degrees below the freezing point in Fahrenheit's thermometer, the lower region of the air was obscured by a perpetual cloud, which was very thick in the morning, thinner towards noon, and thicker again at night\*.

Mists and dew will, generally speaking, be the greatest when the difference between the heat of the air in the day time, and at night, is the greatest, because the hotter the day, the greater is the quantity of water which is dissolved; and the colder the night, the greater will be the

\* Novi Commen. Petrop. Tom. VI. p. 429.

the quantity which is precipitated. It often happens that there is no mist observable towards the close of the day; this may be occasioned, either by there being little difference in the heat of the air at noon, and at night; or, though that difference be considerable, yet the air may chance not to be saturated with water, and in that case it may, even in the night, be warm enough to retain all the water it had dissolved in the day time. In cold weather the breath of animals becomes visible, because the air is not warm enough to dissolve the moisture which is exhaled from the lungs \*.

VOL. III.

F

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\* The breath is visible if the temperature of the air be colder than 61 degrees. *Caval. on Air*, p. 400. The degree of cold in which it is visible, depends partly on the humid or dryness of the air.



It is not unusual for a river in winter time, to be much warmer than the air, hence the vapour which rises from the river is condensed, the air not being able to dissolve it, and a cloud or mist of small elevation, is seen to accompany the river in its course; this appearance ceases, as soon as the river is frozen, because the ice, though it be subject to evaporation, yet it does not yield so much vapour as water does\*.

A cubic inch of rock salt, nitre, or any other kind of salt, is much longer in being dissolved, when it is in a compact state, than when it is reduced into a fine powder, because the salt, when in the form of a powder,

\* Angara-fluvius nocte glacie consistit, quo facto *nebula* illa perpetua, huc usque ex fluvio hoc evecta, cessavit. Novi Comm. Petrop. Vol. VI. p. 436.

der, has a much larger surface exposed to the action of the water, than if it was in one solid lump. In like manner, the air will dissolve any definite quantity of water sooner, when the surface of the water is increased by its being in the form of a vapour, than it would do if the water was either in the form of ice, or in its ordinary fluid state. The smoke of a chimney consists principally of water, in the state of vapour, and it is really astonishing, to see how quickly, in particular states of the atmosphere, it is dissolved in the air.

It has been remarked, that the smoke of mount *Vesuvius* is much more strong and visible in rainy, than in fair weather\*; if this phe-

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nomenon

\* Lett. sur la Mineral. par M. Ferber, p. 188.

nomenon does not proceed from the greater quantity of water, which is raised from the mountain in wet, than in dry weather; it may be accounted for, from the greater facility with which aqueous vapours are dissolved in a dry serene air, than in one which is so saturated with water that it can dissolve no more; which is the case, in general, of air, which parts with its water, in the form of rain or mist.

In riding upon wet sand in a hot day, a kind of tremulous motion in the air, to the height of a foot or more above the sand, may be observed; this appearance may proceed from hence, that the water in rising from the sand, is not immediately dissolved in the air. A similar appearance may often be observed on land,  
 espe-

especially in corn fields towards autumn; the water which is exhaled from the standing corn, not mixing itself at once, so effectually with the air, as to constitute with it an apparently homogeneous fluid. Something of the same kind happens when either saline solutions, wines, or vinous spirits of any kind, are poured into a glass of water, the compound fluid must be agitated, or the mixture will not at first be uniform.

The quantity of water contained in the air, even in the driest weather, is very considerable. We may be said to walk in an ocean; the water indeed of this ocean does not, ordinarily, become the object of our senses; we cannot see it, nor, whilst it continues dissolved in the air, do

we feel that it wets us ; but it is still water, though it be neither tangible nor visible ; just as sugar, when dissolved in water, is still sugar, though we can neither see it nor feel it.\*

Some philosophers have doubted, whether the weight of the air may not chiefly be attributed to the water which is constantly suspended in it\*. But whether this conjecture be admitted or not, the power which the air has of keeping a great quantity of water dissolved in it, may very properly be applied to the illustration of that text, in which it is said, *God divided the waters which were under the firmament, from the waters which were above the firmament †*, without having recourse, with *Episcopus*,

\* Boerh. Chem. Vol. I. p. 461.

† Gen. i. 7.

*copius*, to the very unphilosophical supposition of the blue sky being a solid substance composed of congealed water \*. Some are puzzled to find water enough to form an universal deluge; to assist their endeavours it may be remarked, that was it all precipitated which is dissolved in the air, it might probably be sufficient to cover the surface of the whole earth, to the depth of above thirty feet.

The air not only dissolves water, but various other vapours, which con-

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\* *Extima sive suprema hujus aëris regio attingit fornicem illum cæruleum, in quo postea die quarta stellæ fixæ collocatæ fuerunt; qui fornix cæruleus mihi esse videtur aquarum in altum elevatarum, et crystalli in morem seu condensatarum, seu congelatarum, cæruleoque colore radiantium, compages. Epist. Inf. Theol. Lib. iv. c. 3.*

sist partly of water, and partly of volatile salts and oils. All vegetables, whether aromatic or not, are found to perspire very greatly, and the matter which they perspire, could it be condensed, would, probably, be so far different from pure water, as to have both a taste and smell. The matter perspired by animals, without sweating, consists principally of water, but the water is strongly impregnated with odorous particles. It has been said of *Baron Haller*, that he could smell the perspiration of old people, at the distance of ten yards; this is by no means incredible, for the human body is constantly enveloped in an invisible cloud, arising from the great quantity of matter which is insensibly perspired. *Sanctorius* estimates the *sensible* excretions of a

7                      person

person who eats and drinks 8 lbs of food in 24 hours, at 3 lbs, and the *insensible* perspiration at 5 lbs; but if we suppose the insensible perspiration in this climate (which is colder than that of *Venice*, where he made his experiments) to amount only to one half of our food, we cannot but conclude, that it must form a great cloud around us; for 4 lbs of matter converted into a vapour as heavy as air, would occupy a great space, amounting to above 50 cubic feet. The heat of the human body is generally between 90 and 100 degrees; this degree of heat is sufficient to raise from it, by a kind of distillation, a copious vapour, which would become visible, if the heat was increased; I remember having been greatly heated and fatigued in ascending



cending the ladders from the bottom of the copper mine at *Eaton*; when I got to the top I observed, by the light of a candle, a thick vapour reeking from the body, and visible around it, to the distance of a foot or more.

The disposition of the air for dissolving either pure water, or the matter perspired by vegetables, or animals, is very various, depending chiefly on its *density*, *heat*, and *dryness*. The power which dogs have of scenting the animal they are in pursuit of, must be much affected by this disposition of the air; for the air through which the animal has passed, is impregnated with the matter perspired from its body; and this matter may in one state of the air be so speedily dissolved, and so

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much

much as it were diluted with air, as to make either no impression, or a very slight one, on the olfactory nerves of the dog; whilst in another, it may make a very sensible one. And if we suppose the perspirable matter not to consist chiefly of water \*, but of such particles as are thrown off by perfumes, without their losing sensibly of their weight, still it will be true, that the state of the air must have a great influence in

\* If the whole body of a naked man, except his mouth and nostrils, was shut up in a glass case, so that no air could enter, the matter of the *insensible* perspiration would, probably, be condensed, and stand as dew on the inside of the glass; and I apprehend it would not differ much from the matter of the *sensible* perspiration, or sweat. But if any one be disposed to consider the insensible perspiration as an uncondensable fluid, or a kind of air similar

in rendering them sensible; since it has been found, that on the tops of very high mountains, where the state of the air is very different from what it is in the valleys below, the most odorous bodies lose either entirely, or in a great degree, their powers of exciting a smell.—The existence of water in air is made apparent various ways.

If a bottle of wine be fetched out of a cool cellar, in the hottest and driest day in summer, its surface will presently be covered with a thick vapour, which, when tasted, appears

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similar to that which arises from vegetable fluids, in a state of fermentation (the heat of fermenting wort being much the same as that of an animal body), still its mixture with the atmospherical air must depend very much on the weight, humidity, and other properties of that air.

to be pure water. This watery vapour cannot proceed from any exudation of the wine, through the pores of the bottle, for glass is impervious to water, and the bottle remains full, and when wiped dry, it is found to weigh as much as when taken out of the cellar. The same appearance is observable on the outside of a silver, or other vessel in which iced water is put in summer time; and it is certain, that the water which is condensed on the surface of the vessel, does not proceed merely from the moisture exhaled by the breathing of the people in the room where this appearance is most generally noticed, because the same effect will take place, if the vessel be put in the open air. Water which is cooled by the solution

tion of any salt, or even spring water, which happens to be a few degrees colder than the air, produces a similar condensation of vapour on the outside of the vessel in which it is contained. These and other appearances of the same kind, are to be explained on the same principle. Warm air is able to retain more water in solution than cold air can; when therefore warm air becomes contiguous to the outward surface of a vessel containing cold liquor, it is presently cooled to a certain degree, and in being cooled, it is forced to part with some of the water which it had dissolved, and this water, ceasing to be suspended by the air, attaches itself to the surface of the cold vessel.

The more ancient philosophers,  
not

not suspecting that water might be dissolved in air, were of opinion that the moisture which they observed adhering to the outsides of vessels, which had been cooled by having snow put into them, proceeded from a transmutation of air into water \*. But there seems to be no more reason for this supposition, than there would be for saying, that water was changed into saltpetre, from observing that water which had dissolved as much saltpetre as it could, in a certain

\* *Naturæ mystas arcano modo, sed facili, æcrem in aquam mediis caloribus cogere docebit abjecta hæc nix, si vitro conicæ figuræ, intra tripodem, apice deorsum vergente suspenso, indatur nivis vel glaciei frustum. Quippe subiecto vasculo excipiuntur, exteriore vitri frigiditate collectæ, et laterum declivitate manantes aquæ guttæ. Bartholinus de Figura Nivis, p. 3. See also Boyle's Works, Vol. II. p. 297.*

certain degree of heat, deposited a part of it, when that degree of heat was lessened.

Another method of proving the existence of water in the clearest air, is, to observe the increase of weight, which certain bodies acquire by exposure to the *open* air. I put upon a plate 8 ounces of salt of tartar, which had been well dried on a hot iron; the day was without a cloud, and the barometer stood at 30 inches; in the space of three hours, from 11 to 2 o'clock in the afternoon, the salt had increased in weight two ounces; in the course of a few days its weight was increased to twenty ounces, it was then quite fluid, and being distilled it yielded a pure water equal in weight nearly to the increase it had acquired from the air,

and therefore it is rightly inferred, that water was the substance which it had attracted from the air.

Strong acid of vitriol is another body which very powerfully attracts humidity from the air. An ounce of this acid has been observed to gain, in 12 months, above six times its own weight \*. The power of the acid to attract water from the air, depends upon its strength, for it may be so far diluted, that instead of attracting any more water from the air, it will, by evaporation, lose a part of that which it had acquired; when it is in this state, its weight varies with the dryness or moistness of the atmosphere, and it becomes, when accurately balanced in a good pair of scales, no bad kind of an hy-

VOL. III.      G      grometer.

\* Newm, Chem, by Lewis, p. 161.



grometer. The time in which any definite quantity of acid acquires its greatest weight from the air, depends partly upon the quantity of water which is dissolved in the air, and partly upon the surface of the acid which is exposed to the air, it having been ascertained by experiment, that the quantity attracted from the air, in a definite portion of time, is greater as the surface is greater. Hence, instead of a twelve months exposure to the air being requisite to make one ounce of acid of vitriol acquire six ounces of water, it might possibly acquire that weight in a few minutes, if its surface was enlarged in a due proportion.

Onions and other bulbous roots, when hung up in a room sheltered from rain and dew, are observed to  
germi-

germinate, and to acquire a great increase of bulk, and it might thence have been suspected, that they attracted much water from the air, and were increased in weight. But though they may increase in bulk, they are found to decrease in weight; the root itself, in becoming rotten, supplies nutriment to the germinating plant; and if it imbibes any thing from the air, it loses that and more by perspiration. An onion on the 26th of January, when it had scarce begun to shew any signs of vegetation, weighed 296 grains; on the 16th of the following May, after having put forth several stems in the open air, it weighed only 145 grains\*.

The increase of weight which the

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human

\* Novi Com. Petrop. Tom. II. p. 225.

human body, in many cases, experiences from the water which the pores of the body suck in from the air, is another very sensible proof of the great quantity of water which is constantly dissolved in the air.

“ Keil has proved, that a young man weakened from want of nourishment, but in other respects healthy, added eighteen ounces to his weight, in the space of one night, and this by the absorption through his pores. Another person has been seen to gain 40lbs. weight, in the same manner, in the space of a day. M. de Haen is of opinion; that dropical patients absorb more than 100lbs. weight every day. It is supposed, that, in general, the body absorbs more than 1lb. every day  
by

by the pores \*." The skin of a middle-sized man is equal to about 15 square feet; and if we suppose the skin of a dropfical person to be 20 square feet, then will each square foot imbibe 5lbs. or pints of water in one day.

In addition to these instances I will subjoin the following account, which was given me by a person of credit and judgment. A lad at Newmarket, a few years ago, having been almost starved, in order that he might be reduced to a proper weight for riding a match, was weighed at 9 o'clock in the morning, and again at 10, and he was found to have gained near 30 ounces in weight in the course of an hour, though he

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had

\* Treatise of Physic by Zimmerman. Vol. II p. 128.

had only drank half a glass of wine in the interval. The wine probably stimulated the action of the nervous system, and incited nature, exhausted by abstinence, to open the absorbent pores of the whole body, in order to suck in some nourishment from the air. Something similar to this was the case of the negro, who, being gibbeted alive, regularly voided every morning a large quantity of urine, but discharged no more till about the same hour the next day\*; the dews of the evening at Charles Town in South Carolina, imbibed by his body, supplying a superabundance of fluids in the night, and a sufficient quantity to support perspiration in the day. It has been observed, that “neither hogs  
nor

\* Medical Transf. Vol. II. p. 103.

nor beasts of burden ever drink in Jamaica, and yet they are continually sweating. The air is so moist, that the absorbing pores of these animals imbibe a sufficiency of water\*." The imbibition of water through the pores of the skin is an acknowledged fact——“ it is well known, that persons who go into a warm bath, come out several ounces heavier than they went in; their bodies having imbibed a correspondent quantity of water†. Part of the utility of medicated and vapour baths, depends upon this principle of imbibition by the pores: and it is said that thirst may be allayed by bathing in warm sea water, the pores

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\* Treatise of Phys. Vol. II. p. 101.

† Goldsmith's Hist. of the Earth, Vol. I. p. 238—398.

imbibing the water, and carrying it to the intestines, but not suffering the dissolved salt to accompany the water.

With respect to the quantity of water suspended in the whole atmosphere, or even in a column of the atmosphere, of a definite basis, incumbent on any particular spot, it cannot be ascertained with precision, unless we knew some method of depriving the air of all the water it contains, and could at the same time make the experiment at different distances from the surface of the earth. For it is not only probable, that a cubic yard of air, contiguous to the surface of the earth, contains at different times very different quantities of water, even at the same place, according as the ground is  
moist

moist or dry, or the temperature of the weather warm or cold; but we have great reason to believe, that at the same instant of time, a cubic yard of air, which touches the surface of the earth, contains as much water as three or four cubic yards, which are situated at the distance of thirty or forty yards above it. For the water which rises from the surface of the ocean, from the perspiration of organized bodies, whether vegetable or animal, or from the mere action of the sun on a moist earth, in being dissolved in the air as soon as it rises, makes the air near the surface heavier than that which is at a distance from it, and on that account the motion of the air, unless it be violent, will not readily mix the lower and heavier air with the higher



higher and lighter, and the lower air will consequently contain more water in a definite bulk, than the higher. To what has in a former Essay been observed on this subject, the following illustration may be added. If into a deep drinking glass half full of water, you gently pour a glass of port or claret, you will see the wine mixing indeed itself slowly with the water, but that part of it which is near the water, will be much more impregnated, in any definite portion of time, with water, than the more remote parts, it will be a considerable time before the water will be uniformly diffused through the wine, if they are left undisturbed; nor does a gentle undulating motion soon mix them, and this difficulty of mixing them would be still much greater,

greater, if there was a greater difference in their respective weights, or if the upper parts of the wine were less dense than the lower. Now this is the case in the air, which is not only above 800 times lighter than water, but its parts, which are far removed from the surface, are much less dense than those which are contiguous to it. That dense air holds more water in solution than rarefied air, is proved from hence; that when common air is rarefied under the receiver of an air-pump, a part of the water which is contained is precipitated, in the form of dew; this answers to the precipitation of salt from a saline solution, when part of the water is taken away, which held the salt in solution. Hence, as cold tends to render the air more dense,

it certainly contributes to its holding more water in solution than it would do, if it was more rarefied under the same degree of heat: but as hot air dissolves more water than cold air, and as air is rarefied by heat, it is evident, that the density and heat of the atmosphere in some measure counteract each other, with respect to the power the air has in dissolving water: the law according to which this power varies, in different degrees of heat and condensation, is not determinable from any experiments which have yet been made.

It may not be improper to take notice, in this place, of an objection which is usually made to the doctrine here advanced,—of water being suspended in the air by solution—It is asserted, that water is as evapor-  
able

able in an exhausted receiver, where there is no air, as in the open air\*. It is certain, that heat will evaporate water, and great degrees of it may probably evaporate it faster *in vacuo* than in the open air, inasmuch as the pressure of the air may tend to obstruct the action of the heat, in converting the water into vapour. Thus, quicksilver is not, I apprehend, evaporable in the open air, yet it has long been remarked to be evaporable *in vacuo*, as may be collected from the little globules of quicksilver, generally found adhering to the upper part of a barometer, and which arise from the vapour which insensibly escapes from the surface of the quicksilver in the tube.

\* Berlin Mem. 1746. Waller de Aëren. Vapo. in vacuo.

tube. But though heat may be one cause of the evaporation of water, the attraction between air and water, upon whatever principle it depends, may be another. The fact moreover, upon which the objection is founded, is very questionable, and not generally to be admitted. A china faucer, which contained 3 ounces of water, lost nothing of its weight under an exhausted receiver in the space of 4 hours; whilst a similar faucer, containing an equal quantity of water, lost, in the same time, in the open air, one drachm and eight grains; the heat of the atmosphere being between 48 and 50 degrees\*.

Many readers are gratified with seeing the general progress of any philo-

\* See Dr. Dobson's ingenious Observations in Philos. Trans. 1777, P. 256.

philosophical opinion, from its being first suggested, till its being generally admitted. The history, indeed, of philosophy, is one of the most pleasing pursuits which a speculative mind can be engaged in, but it requires great leisure and ability to cultivate it with success. It is not every distant hint which he throws out, that can intitle a philosopher to the credit of being the first framer of an hypothesis; nor on the other hand are we hastily to reject the maxim, that "all novelty is but oblivion," inasmuch as we frequently see old opinions putting on the appearance of new discoveries, from their being dressed out in a new form.

Natural philosophy principally consists in exploring, by experiment,  
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the phenomena resulting from the mutual action of different bodies upon each other. These phenomena are innumerable, no arithmetic can reckon up the various ways in which terrestrial bodies may, by natural or artificial means, be brought to operate on one another. To this cause may we attribute the immense number of volumes on experimental philosophy, which have been published in Europe since *Bacon* pointed out the proper method of studying nature. This circumstance, joined to the uniformity which must ever attend the operations of nature in similar circumstances, may justly intitle different men to the honour of having made the same discoveries, it being much easier to make an experiment, which may have been

made before, than to read all that has been written in different ages and countries on natural appearances.

*Doct<sup>r</sup> Halley*, in the year 1691, propos'd to the Royal Society, his opinion concerning the origin of springs: in this tract he expresses himself in the following manner: "The air of itself would imbibe a certain quantity of aqueous vapours, and retain them *like salts dissolved in water*, the sun warming the air, and raising a more plentiful vapour from the water in the day time, the air would sustain a greater portion of vapour, as warm water would hold more dissolved salts, which upon the absence of the sun, in the nights, would be all again discharged in



dews, analogous to the precipitation of salts on the cooling of liquors.”\*

*M. Le Roy* published an ingenious dissertation on the solubility of water in air, in the year 1751; among other experiments, by which he illustrated his hypothesis, he observes, that if a large, new, hollow, globular glass vessel, with a narrow neck, be closely corked up in a clear hot day, the water contained, in the apparently dry air, will be precipitated, and form a dew in the inside of the vessel, whenever the vessel is cooled, and that this dew will vanish, being redissolved by the air included in the vessel, as soon as the air regains its heat.

*Doctor Franklin* further illustrated this principle, of water being soluble  
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\* *Philos. Trans.* No. 192.

in air, in a paper which was read before the Royal Society in 1756, and afterwards printed in his works\*.

In the French *Encyclopedie*, published in 1756, we meet with the following passage—On voit par la combien se trompent ceux qui s'imaginent que l'humidite qu'on voit s'attacher autour d'un verre plein d'une liqueur glacee est une vapeur condensee par le froid : cet effet, de meme que celui de la formation des nuages de la pluie, et de tous les meteors aqueux, est une vraie precipitation chimique, par un degre de froid qui rend l'air incapable de tenir en dissolution toute l'eau dont il s'etoit charge par l'evaporation dans un tems plus chaud ; et cette precipitation est precisement du

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meme

\* Franklin on Elec. p. 182.

meme genre que celle de la creme de tartre, lorsque l' eau qui la tenoit en dissolution s' est refroidie\*.

*Muschenbroek*, amongst other causes which he assigns for the suspension of vapour, evidently alludes to the solution of water in air, and compares it to the solution of salts in water.†

But though a great many philosophers had spoken of the solubility of water in air, before *Doctor Hamilton*, yet in justice to him it must be owned, that no one has treated the subject more distinctly, or applied it more successfully to the explanation of various phenomena than he has done, in an essay which was read to the

† Ency. Fran. T. VI. p. 283. Fol. Ed.

† Introduct. ad Phil. Nat. Vol. II. p. 965, pub. 1769.

the Royal Society in 1765, and afterwards published with other essays, by the same author.\* The reader will be very well pleased with seeing this principle illustrated in an essay by Mr. White, published in 1771, in the elegant collection of Georgical Essays by *Doctor Hunter* †.

\* Philos. Essays by Hugh Hamilton, D. D. F. R. S.

† Georgical Essays by Doctor Hunter, Vol. II. p. 15.



## ESSAY IV.

OF COLD PRODUCED DURING THE  
EVAPORATION OF WATER, AND  
THE SOLUTION OF SALTS.

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ON the 27th of March 1779, when the weather had been for some time very dry, I put a thermometer into a glass of water, which had been heated to 87 degrees, by standing exposed to the direct rays of the sun. The thermometer was then taken out, and its bulb was held opposite to the sun, which shone very  
H 4 bright;

bright ; as the bulb grew dry by the evaporation of the water, the mercury in the thermometer sunk very fast ; it continued for a moment stationary at 76 degrees, and then it rose rapidly to 90 ; so that 11 degrees of cold had been produced during the evaporation of the water.

On another day in the same month, when the heat in the shade was 68 degrees, I put a thermometer into a glass of water, it stood at 50 degrees ; upon taking it out, the mercury, instead of sinking from the effect of evaporation, began *immediately* to rise from the effect of the heat of the atmosphere upon it. I put the thermometer into the same water, heated to 55 degrees, and taking it out, the mercury continued *stationary* for some time, and afterwards it began  
to

to rise. It was put into the same water heated to 58 degrees, and upon being taken out, the mercury did not either rise or continue stationary, but it sunk one degree; when the water was heated to 60 degrees, the thermometer, upon being taken out, sunk 3 degrees before it began to rise. These experiments were all made in the shade, and it seems as if we might conclude from them, that 57 was the degree of heat in the water, in which the cold produced by evaporation, was just equal to the heat produced by the atmosphere which then surrounded the ball of the thermometer.

The degree of cold produced by evaporation, depends, probably, upon the quickness with which that is accomplished: now the quickness

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with



with which water, of a definite temperature, is evaporated, is influenced, partly by the degree of heat prevailing in the atmosphere; partly by the wind blowing upon the thermometer; partly by the dryness or moistness of the air; and by other causes.

September 30th of the same year, when the heat in the shade was 64 degrees, and the heat of the water 60, the thermometer, upon being taken out, stood stationary for three minutes, and then it rose; there was a gentle south wind. On the next day there was a cold dry wind from the north, the water and air were both at 56 degrees, and the thermometer on being taken out sunk to 52.

Spirits of wine, ether, and many other fluids, produce cold by being  
eva-

evaporated, and they produce a much greater degree of cold than water, in consequence, probably, of their being more evaporable. Thus, vitriolic ether\*, which is one of the most volatile fluids in nature, has been observed to lower *Reaumur's* thermometer 40 degrees below the freezing point (which answers to 90 degrees of Fahrenheit's scale)†. The experiment is most commodiously made, by applying a piece of fine linen wetted with ether upon the bulb of the thermometer, accelerating

\* Ether is made by distilling a mixture of spirits of wine and oil of vitriol.—Ether may be made also by distilling spirits of wine with the several acids of nitre, sea salt, and vinegar, and it is then called the nitrous, marine, acetic ether.

† Chem. Dict., art. Ether. Or Manuel de Chymie, par. M. Baumé, p. 375.

ing the evaporation by blowing on the linen with a bellows, and moistening the linen as it becomes dry, or exchanging it for a fresh piece which is wetted with ether. Whoever attempts to ascertain the degrees of cold respectively produced by different fluids, would do well to remark particularly the state of the atmosphere with respect to other circumstances, as well as to its heat.

Sailors have a custom, in a calm, to hold a wet finger up into the air, and if one side of it, in drying, becomes colder than another, they expect wind from that quarter. This custom is not without its foundation; for an almost insensible motion of the air will evaporate the water from one side of the finger sooner than

than from another, and thus produce a degree of cold.

There is a similar experiment, by which any one may convince himself that cold is produced by evaporation ; let him wet a finger by putting it in his mouth, and then hold it up in the air, even in a warm room where there is no current of air, he will find that it grows cold as it becomes dry by the evaporation of the humidity.

“ The method our gentlemen make use of to cool their liquors, is to wrap a wet cloth round the bottle and set it in the land wind : and, what is very remarkable, it will cool much sooner by being exposed thus to this burning wind, than if you take the same method, and set it in the

the cold sea-breeze."\* — The cold is produced by the evaporation of the water from the wet cloth, and as the *hot* land-wind will evaporate the water sooner than the *cold* sea-breeze, it is not to be wondered at, that the liquor is sooner cooled when placed in the former wind than in the latter.

"*Kempfer* relates, that the winds are so scorching on the borders of the Persian gulph, that travellers are suddenly suffocated, unless they cover their heads with a wet cloth; but if this be too wet, they immediately feel an intolerable cold, which would become fatal to them if the moisture were not speedily dissipated by the heat."† The cold, which is

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\* *Ives's Voy.* p. 77.

† *Treatise of Physic by Zimmerman, Vol. II. p. 151.*

produced by the act of evaporation, ceases as soon as that is finished, by the cloth becoming dry.

The manner of making ice in the East Indies, has an evident dependence on the principle of producing cold by evaporation here mentioned. On large open plains the ice makers dig pits about 30 feet square and 2 deep; they strew the bottoms of these pits, about eight inches or a foot thick, with sugar canes, or with the dried stems of Indian corn. Upon this bed they place a number of unglazed pans, which are made of so porous an earth, that the water penetrates through their whole substance. These pans, which are about a quarter of an inch thick, and an inch and a quarter deep, are filled, towards the dusk of the evening

ing in the winter season, with water which has been boiled, and then left in that situation till the morning, when more or less ice is found in them, according to the temperature of the weather; there being more formed in *dry* and *warm* weather, than in that which is cloudy, though it may chance to be colder to the feel of the human body.\* Every thing in this process<sup>a</sup> is calculated to produce cold by evaporation; the bed on which the pans are placed, suffers the air to have a free passage to their bottoms, and the pans, in constantly oozing out water to their external surface, will be cooled in consequence of that water being evaporated by a gentle stream of *warm dry* air, the power of  
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\* Philof. Transf. for 1775, p. 252.

the air to evaporate water depending much upon its warmth and dryness.

They have a kind of earthen jar in some parts of Spain, called *Buxaros* which are only half baked, and the earth of which is so porous, that the outside is kept moist by the water filtering through ; though placed in the sun, the water in the pots remains as *cold as ice* :\* and it probably is colder from the jar being placed in the sun, because the evaporation is thereby increased.

The *Blacks* at *Senegambia* have a similar method of cooling water. “ They fill tanned leather bags with it, and hang them up in the sun ; the water oozes more or less through the leather, so as to keep the outward surface of it wet, which, by its quick

\* Swinburne's Trav. p. 305.



quick and continued evaporation, occasions the water within the bag to grow considerably cool.”†

It is common enough for labouring people, in the height of summer, to drink several quarts of beer or other beverage in a day; this quantity is principally discharged from the body by perspiration; and the cold which is generated during the evaporation of the sweat, greatly contributes to keep the body cool. Thus has Providence contrived to render the heat of the torrid zone less insupportable to the inhabitants; an intense heat bathes the body in sweat, but the sweat being evaporated by the same heat which occasioned it, a degree of cold is generated on the

† *Philos. Trans.* 1780. p. 486.

the surface of the body, which would not otherwise have been produced.

It seems reasonable to attribute the cold, which is produced in these and other similar circumstances, to the evaporation of the water, rather than to any other cause ; because when the bulb of a thermometer is wetted with different fluids, the cold produced has a manifest dependance on the evaporability of the fluid with which it is wetted. Thus, more cold is produced when the thermometer is wetted with spirits of wine, than when it is wetted with water, because spirits of wine are more evaporable than water ; and more is produced when it is wetted with ether, than with spirits of wine, because ether is more evaporable than spirits of wine. No cold is pro-

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duced

duced when the thermometer is smeared with linseed oil, or other oils of a similar nature, because these oils are not sensibly evaporable in the ordinary heat of the atmosphere. Strong acid of vitriol when exposed to the air, instead of losing any thing of its weight, acquires an increase, by attracting the humidity of the atmosphere; and as strong acid of vitriol when mixed with water, generates a degree of heat, so the bulb of the thermometer, when wetted with strong acid of vitriol, instead of being cooled, is warmed, and the mercury ascends, in consequence of the heat produced from the union of the acid of vitriol with the water contained in the air.

When water is resolved into vapour, by the violence of a fall from

a con-

a considerable height, the air will dissolve it sooner ; and in dissolving it sooner, it will, probably, produce more cold than it would have done, if the surface of the water had not been broken : hence natural and artificial cascades, may, probably, be serviceable in cooling the air surrounding them. This observation is purposely expressed in different terms, because, having more than once sprinkled the floor and sides of a room with water in the summer time, when the heat of the air in the room and of the water was 68 degrees, I could not observe that a thermometer, hung in the middle of the room, changed its degree of heat whilst the room grew dry. In very hot climates the effect may, probably, be different ; thus we are told, that in

the island of *St. Lewis*, in the river *Senegal*, “ water poured on the floor of a room for the purpose of cooling the air, is dried up in an instant, and there is *some effect on the thermometer* placed in such a room,”\*

This phenomenon of producing cold by evaporation, had been mentioned by *M. Amontons* in the year 1699.† It had been noticed also by *M. Mairan* in 1749,‡ and by *Musschenbroek*, in his *Essai de Physique*. Professor *Richman*, at Petersburg, gave an account of several experiments, which he had made on this subject in 1747 and 1748,|| but he did

\* *Philos. Trans.* 1780. p. 485.

† *Mem. de l' Acad. des Scien. a Paris*, 1699.

‡ *Dissertation sur le Glace*.

|| *Novi Comment. Petrop. Tom. I.* for 1747 and 1748.

did not explain the sinking of the mercury in the thermometer, whilst its bulb grew dry, on the principle of evaporation. Dr. *Cullen* has very particularly illustrated this principle, in a paper published in 1756; and he has there shewn that the cold produced was greater, when the evaporation was made in vacuo, than in the open air.\* Lastly, Professor *Braun*, to whom the world is indebted for the discovery of freezing quicksilver, has made a further investigation of this matter, by publishing a table of the degrees of cold produced during the evaporation of different fluids.†

During the solution of salts in water

\* *Essays, Physical and Literary*, Vol. II. Edinb. 1756. p. 145.

† *Novi Commen. Petrop.* Tom. X. 1764.

ter either cold or heat is generally produced, but more commonly cold. Fixed alkaline salts, Glauber's salt, and white vitriol, produce small degrees of heat during their solution. Sal ammoniac produces the greatest degree of cold, of any salt hitherto known.

When Fahrenheit's thermometer stood at 68 degrees, both in the open air, and in the water which was used for the experiments, I saturated equal portions of water with sal ammoniac, with saltpetre, and with sea salt. The sal ammoniac made the mercury sink from 68 to 42 degrees, hence, 26 degrees of cold were produced; the nitre produced 17 degrees, and the sea salt produced only 2 degrees of cold. I repeated the experiment with the sea salt several

ral times, and with different sorts of it, but I could never observe that it produced above 2 or at most  $2\frac{1}{2}$  degrees of cold. The experiments with sal ammoniac and saltpetre, agree very well with those made by M. *Eller*, and mentioned in the Berlin memoirs for 1750; since he produced almost 27 degrees with sal ammoniac, and 18 with saltpetre. *Boerhaave*, indeed, made the thermometer descend through 28 degrees by dissolving sal ammoniac in water; but he had reduced his salt to a very fine powder, and dried it well before he used it; and a difference in the fineness of the powder to which the salts are reduced before they are dissolved, may make a difference of a degree or two in the cold produced; for the finer the salt,  
the



the more surface has the water to act upon, and the quicker will the solution be performed ; and as the cold is produced only by the act of solution, the sooner that is accomplished, the less effect will the heat of the atmosphere have, in restoring to the water, during the time of the solution, any part of the heat it may have been deprived of, during the immediate action of the water upon the salt.

Does any given kind of salt, during its solution in water, produce the same number of degrees of cold, whatever be the temperature of the water before solution ? I have only endeavoured to resolve this question with respect to sal ammoniac, and it seems to me that the quantity of cold produced, is not influenced by the temperature.

temperature of the water. In the summer season when the temperature of the air, water, and sal ammoniac were each of them 70 degrees, the water sank during the solution, of as much sal ammoniac as would saturate it, to 44 degrees, or through 26 degrees. I thawed some snow in winter, the thermometer stood in the snow water at the freezing point, or at 32 degrees; by putting sal ammoniac, which was equally cold, into the water, the thermometer descended during solution to six degrees, or through 26 degrees.

The possibility of freezing water in the middle of summer, is rightly enough inferred from this experiment. In a tub, suppose of 3 feet in diameter, place a bucket, a little smaller than the tub, of 1 foot in diameter;

meter ; in the bucket hang a Florence flask, or a flat lavender water bottle, so that the mouth of the bottle may be above the rim of the bucket : fill these vessels with water heated, suppose, to 70 degrees. Saturate the water in the tub with sal ammoniac, then will the 70 degrees of heat be reduced to 44, the water losing, during the solution of the salt, 26 degrees. The water in the bucket being surrounded with this cold fluid, will itself be cooled ; suppose it to be cooled only to 50 degrees, then by saturating it with sal ammoniac, it will lose 26 degrees more of its heat, and be cooled to 24 degrees. The water in the bottle being immersed in a fluid, heated only to 24 degrees, will soon be cooled below  
the

the freezing point or 32 degrees, and consequently will concrete into ice.

The cold, in all these cases, is generated only during the time of the solution. The water recovers the temperature of the atmosphere sooner or later, according as its quantity is less or greater, and as the surface exposed to the air is greater or less; it is here supposed, that the heat of the atmosphere remains the same. The different degrees of cold produced by different salts, do not depend upon any general cause which has yet been discovered, nor is there any very satisfactory reason given for these, and other similar productions of cold or heat. The time may come when we shall be able to comprehend the reason why the acid of nitre ~~has~~ such different effects when mixed

mixed with snow from what it has when mixed with snow water ; when mixed with snow water it excites a very great degree of heat ; and when mixed with snow it produces the greatest degree of cold that has ever yet been observed \*. *Rerum natura sacra sua non simul tradit. Initiatos nos credimus, in vestibulo ejus hæremus. Illa Arcana non promiscuè nec omnibus patent ; reducta et in inferiore sacratio clausa sunt. Ex quibus aliud hæc ætas, aliud quæ post nos subibit, adspiciet.*

\* Vol. I. p. 267.

## E S S A Y V.

OF THE DEGREES OF HEAT IN WHICH  
WATER BEGINS TO PART WITH ITS  
AIR, AND IN WHICH IT BOILS.

**T**HE air bubbles which, in summer time, adhere to the insides of decanters, water glasses, and other vessels filled with water, cannot have escaped the observation of any one; I have endeavoured to ascertain the degree of heat in which these bubbles begin to be formed.

Into

Into a water glaſs filled with water I immerſed a thermometer ; the heat of the water was 64 degrees ; the water was ſet in a cloſet, where the ſun never ſhone, for two days ; the heat remained much the ſame during that period, and there was no appearance of bubbles. The glaſs, with the immerſed thermometer, was then ſet in the ſun, and when the heat amounted to about 90 degrees, ſeveral air bubbles were found adhering to the graduated ſide of the thermometer, and ſome were beginning to be formed on the bottom and ſides of the glaſs.

Having frequently ſeen the inſides of veſſels containing water, ſtudded with bubbles, when the heat, it was apprehended, was much leſs than 90 degrees ; I put a thermometer

ter into a water-glass at a time when it abounded with bubbles, and found that the heat of the water was not above 64 degrees.

The result of this experiment being very different from that of the preceding, in which the air did not begin to separate itself from the water till the heat was about 90 degrees, I was for some time at a loss how to account for the difference; recollecting, however, that the water, which required 90 degrees of heat before it parted with its air, was pumped from a well fed by a stream, which had run four miles in the open air; and that the other water, which let go its air at 64 degrees, was pumped from a well fed by subterraneous springs, I attributed the difference in the degree of heat



requisite to make these waters part with their air, to the different qualities of the waters.

In order to try these waters under similar circumstances, two water-glasses were filled, one with common well water, another with that which had been supplied by the stream; on being exposed to the air, bubbles began to be formed in the well water when the heat amounted to 60 degrees; the other did not part with any of its air in the same degree of heat.

I was at first disposed to think, that these experiments pointed out a general difference between river water and well water, with respect to their disposition for retaining or parting with their air; but the following experiment, made at a different sea-

son of the year, convinced me that the conjecture was not well founded.

In November, when the heat of the air had been for some time about 50 degrees, I took three water-glasses, one was filled with rain water immediately after it had fallen, another with the common well water, the third with the water which came from the stream: the heat of these several waters was the same, namely 48 degrees: they were all gradually warmed, by setting the water-glasses in hot water, and they all began to exhibit bubbles when the heat was about 60 degrees: I thought the rain water shewed the most bubbles.

Hence it is plain, that the stream water does not differ from rain or well water, except accidentally, as to the degree of heat in which it parts

with its air. The first experiment, in which the bubbles were not formed till the heat was 90 degrees, was made after there had been several days of very hot weather, and the water in being exposed, during its course, to the action of the sun, had probably lost a considerable portion of its air before it arrived at the well. All river water has a vapid taste in summer-time, which is in part, probably, occasioned by having lost some of its air, in consequence of its being exposed to the rays of the sun. Water-drinkers are desirous of having water fresh from the well, especially in summer-time; and not without reason, for the heat in that season being generally above 60 degrees at our principal meal time, the water, if it has been long exposed

to

to the air, must have suffered a change of quality, not only from its increase of heat, but from a consequent loss of a portion of its air. The water which supplies the warm bath at *Matlock*, and which is drunk by invalids, is 68 degrees warm; hence it has lost a part of the air which it would naturally contain, and, except in very hot weather, it does not exhibit any air-bubbles in the decanters.

The air begins to be *visibly* separated when the heat is about 60 degrees; but it begins, probably, to be *invisibly* separated when the heat is much less: and the least heat will be requisite to separate it, when the weight of the atmosphere is the least.

Philosophers have invented various methods, equally conclusive, of

shewing, that water, in its ordinary state, contains dissolved in it a portion of air. And they have shewn, that water which has lost a portion of this air, either by being *frozen*, or *beated*, or by long continued *agitation*, or by other means, has the property of re-absorbing as much air from the atmosphere as it had lost; and they have shewn, that this absorption is the strongest at first, and becomes less and less powerful, as the water becomes more and more impregnated with air. These and similar observations render it probable, that water is as capable of dissolving a certain portion of air, as it is of dissolving a certain portion of any particular kind of salt. The quantity of air, which water is capable of dissolving and retaining in solution, depends partly upon

upon the temperature of the water, partly upon the weight of the atmosphere, and partly, I conceive, upon the water's purity. From these circumstances, as well as from some others which might be attended to in making the experiment, it has happened, that authors have given very different accounts of the quantity of air contained in water. *Boerhaave* has an experiment\*, from which he infers, that there may be separated from water a quantity of air equal in bulk to the water; the experiment is ingeniously contrived, but the conclusion, I think, is liable to some objections. The *Abbé Nollet* says, that water which has been previously purged of air, absorbs in six days, one thirtieth of its bulk†.

K 4

*Docton*

\* Boer. Chem. Vol. I. p. 521.

† Hist. de l'Acad. 1743.

*Doctor Hales* obtained by distillation one cubic inch of air from fifty-four cubic inches of water\*. *Mr. Eller* is of opinion that the portion of air contained in water does not exceed the 150th part of its bulk†. *Dr. Priestley* found that a pint of his pump water contained about one fourth of an ounce measure of air, that is, the bulk of the water was to that of the air it contained, as 64 to 1 §. *M. Fontana* says, that the water of the *Seine* at *Paris*, after being long boiled, absorbs in forty days one twenty-eighth of its bulk of common air ‡. Lastly, *M. Cavallo* observes, that in a temperate degree of heat, and when the barometer is about

\* *Veg. Stat.* c. 6. † *Berl. Mem.* 1750.

§ *Philos. Trans.* 1772, p. 248.

‡ *Philos. Trans.* 1779, p. 439.

about  $29\frac{1}{2}$  inches, water absorbs about one fortieth of its bulk of common air\*.

It has been remarked in another place†, that the *atmospherical* air consists, in part, of *fixed* air; and some of the most striking differences between fixed and atmospherical air were there mentioned. If a bubble of atmospherical air of a definite bulk, suppose it equal to eleven pints, be exposed to the action of a sufficient quantity of water, which has been purged of its air by boiling, the *whole* of the bubble will, in a proper length of time, be absorbed by the water; but when about seven pints, or even a less portion, have been absorbed, the remaining part will

\* Cavallo on Air, p. 213.

† Vol. II. p. 247.



will resemble fixed air in this—that a candle will not burn in it\*. It is very probable that water which has not been boiled may have a similar effect under certain circumstances. —“ The wells at *Utrecht* are from 8 to 20 feet in depth ; it has been the custom to make use of pumps to raise the water, and they are then covered over with a kind of arch. When, after a certain period of time, the wells are opened, on any account, it is necessary to leave them uncovered for 12 hours, before any person descends into them; whoever should venture to go down into them sooner, would expose himself to immediate death. The air of these wells extinguishes candles like that acquired from fermentation or  
effe-

\*Philos. Trans. 1772, p. 247.

effervescence \*." — Stagnating air, which has brooded, though but for a short time, even over running water, is found to be so greatly altered in its quality, that it will extinguish flame, though it be sufficiently pure to support animal life. I was informed of this fact by a miner in Derbyshire, who had frequently verified it by his own experience. In order to free a mining district from water, they frequently dig for miles together subterraneous aqueducts; supporting the sides and roof with timber or stone. The mouths or outlets of these aqueducts or *foughs* being below the level of the district to be drained, there is a constant stream of water flowing through them. These *foughs* are many of them

\* Lavoisier's Essays, p. 118.

them high enough for a man to walk upright in them, the water reaching to his middle or higher; and men with lighted candles frequently walk through them from one end to the other, in order to prevent obstructions; it sometimes however happens, that by the falling in of the roof, or other accidents, the fough is in part dammed up: when this is the case, the water beyond the place where the obstruction is, rises to the roof of the fough, and thus prevents a circulation of air, though there is still a discharge of water through the mouth of the fough. When an accident of this kind happens, men are sent with candles in their hands to find out and remove the obstruction, but before they have walked fifty yards from the mouth of the

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fough,

though, the candles go out, though they perceive no difficulty in breathing, and this extinction of the candles will take place in 24 hours after the stoppage of the water has commenced.

*Fabrenheit, Boerhaave*, and other philosophers had observed, that the degree of heat, requisite to make water boil, was variable according to the purity of the water, and the weight of the atmosphere. Within the usual limits of 28 and 31 inches in the barometer, *Boerhaave* was of opinion\*, that there would be a variation in the heat of boiling water, amounting to 8 or 9 degrees. This subject has of late been examined with great accuracy by Mr. *de Luc*, and Sir *George Shuckburg*; and Mr. *Cavallo*

\* *Chem. Vol. I. p. 171.*

*Cavallo* has given us the result of their experiments in the annexed table, which is formed according to the scale of *Fahrenheit's* thermometer\*.

## T A B L E.

| Height of the<br>Barometer. | Heat of boiling water<br>according to |                           |
|-----------------------------|---------------------------------------|---------------------------|
|                             | Mr. de Luc                            | S. G. Shuckburg           |
|                             | Parts of<br>a Deg. deg.               | * Parts of a<br>Deg. deg. |
| 26                          | 205,17                                | 204,91                    |
| 26 $\frac{1}{2}$            | 206,07                                | 205,82                    |
| 27                          | 206,96                                | 206,73                    |
| 27 $\frac{1}{2}$            | 207,84                                | 207,63                    |
| 28                          | 208,69                                | 208,25                    |
| 28 $\frac{1}{2}$            | 209,55                                | 209,41                    |
| 29                          | 210,38                                | 210,28                    |
| 29 $\frac{1}{2}$            | 210,2                                 | 211,15                    |
| 30                          | 212                                   | 212                       |
| 30 $\frac{1}{2}$            | 212,79                                | 212,85                    |
| 31                          | 213,57                                | 213,69                    |

\* *Cavallo on Air*, p. 215.

The

The following experiment is curious in itself, and it illustrates both the nature of boiling in general, and what is here advanced relative to the heat of boiling water under different pressures of the atmosphere. I hit upon it many years ago, when I had another object in view. My design was, to exhibit a striking instance of the increase of dimensions produced in fluids by various degrees of heat: in order to this, I took a large glass vessel, resembling in shape such mercurial thermometers as have a bulb at the bottom\*; the bulb of this vessel held above a gallon, and the stem had a small diameter, and was above two feet in length. Into this vessel I poured  
boiling

\* A vessel of this shape is usually called a *Matrafs*.

boiling water, and having filled it up to the very top of the stem, I corked it with a common cork as close as I could. The water and the cork were at first contiguous to each other; but in a very little time the water began to grow cold, and as it grew cold, it contracted itself and sunk very visibly in the stem; and thus the first intention of the experiment was fully answered. But an unexpected phenomenon presented itself,—the water, though it was removed from the fire,—was growing cold,—and had for some time entirely ceased from boiling, began to boil afresh very violently, the bubbles were large and numerous, and continued to ascend into the space between the surface of the water in the stem, and the cork, where they

they burst, for above two hours. When a hot iron was applied to that part of the stem, through which the water, in contracting itself, had descended, the ebullition presently ceased; it was renewed when the iron was removed; and it became more than ordinarily violent, when, by the application of a cloth dipped in cold water, that part was cooled. There is no great difficulty in accounting for these several appearances: by the sinking of the water in the stem a *kind of vacuum* is left between its surface and the cork; water and other fluids boil with less degree of heat, when the pressure on their surface is diminished; here the pressure of the atmosphere is wholly removed by means of the cork, and the water continues to boil, though its heat be



constantly decreasing. The interval between the water and the cork is not, as will be shewn presently, a *perfect vacuum*; it is occupied either by the vapour of the water, or by a small portion of air, or by both; heat increases the elasticity of both air and vapour, and thus augments the pressure upon the surface of the water, hence, the ceasing of the ebullition on the application of the hot iron; cold diminishes the elasticity of air, and condenses vapour, and thus, the pressure upon the surface being lessened by the application of the cold cloth, the ebullition of the water became more violent. When the water ceased boiling I poured it on the bulb of a thermometer, and found that its heat was only 130 degrees.

Another

Another circumstance deserving of notice remains to be mentioned. When the water was become cold, it had sunk through the whole stem, and through part of the bulb; I then inverted the vessel which contained it, into a tub of water, and observed upon the bottom of the bulb a large circular spot void of water. I considered this spot as a perfect vacuum, for it answered to the space which the water, in contracting itself, had deserted; and the vapour which, whilst the water was warm, might have been supposed to occupy that space, I was, persuaded, was condensed by the cold: in order to see whether it was a *vacuum* or not, I pulled out the cork, whilst it was under the surface of the water into which the vessel was inverted, being

L 2

certain

certain that if it was a vacuum, it would be instantly filled with water, which the pressure of the atmosphere would make to ascend through the stem. In fact, the circular spot was greatly diminished by the ascent of the water, but never (for the experiment was often repeated) taken wholly away. What remained must have contained either air, or some other fluid, whose elasticity was a counterpoise to the pressure of the atmosphere, on the surface of the water in the tub. It would be too hasty a conclusion, from this circumstance, to attribute the formation of the bubbles to the particles of air, from which water cannot be separated by long boiling\*; for it may be,

\* *Licet diu ebullierit aqua non erit aeris expers. Muschen. de Aqua.*

be, that this small portion of air arose from the substance of the cork; or from the air in the water of the tub, that water having not been boiled; or it may have been intangled in the parts of the boiling water, as it was poured into the vessel, and not have had time to escape before the cork was inserted; or, lastly, which is the least probable supposition, the vapour arising from the water may not be capable of being totally condensed.

The phenomenon of the boiling of fluids is not very satisfactorily explained. It is clear, I think, from the experiment of which I have given an account, that it cannot be attributed, in all cases, either to the escape of air from the interstices of water, or to the matter of fire, as it

is called, pervading the water; for the water continued boiling for two hours after it was removed far from the fire; and the air, if it contained any, was utterly inadequate to the formation of the numerous bubbles. *Boerhaave* has remarked, that bubbles of the kind here spoken of contain no air, but he has not assigned the cause of their origin: *Dr. Hooke* ascribes them to the subtle parts of the water, which, when the pressure of the air is removed (probably by means of an air pump), are able to acquire the form of vapours, by that small degree of heat which is left in the ambient air\*: and other philosophers † have adopted this idea, without hinting at, what *Hooke* supposed,

\* See *Birch's Hist. of the Royal Society.*

† The Abbe Nolle and *Dr. Hamilton.*

posed, a different degree of volatility in the parts of the water.

From what has been advanced we may conclude, that the *Almighty*, when he separated the chaotic mass into air and water, did not render these two oceans of matter so wholly heterogeneous from each other, as that they should be incapable of contracting any union together; they have, on the contrary, such a disposition to unite, as seems to indicate their having had a common origin; and were it not for the intervention of heat, they would, probably, unite, and again compose a common mass. The water on the surface of the earth, is constantly replete with air, and the atmosphere is replete with water. The numerous tribe of aquatic ani-

imals, which inhabit the ocean of water, would perish, if it contained no air; and it is not an improbable conjecture, that the animals which exist in this ocean of air, would perish if it contained no water. The air, moreover, by being absorbed into the water, and afterwards separated from it by the action of the sun, to which it is daily exposed, is rendered abundantly more fit for animal respiration than common air; and this purified air (the quantity of which, considering the great extent of the surface of the earth which is covered with water, must be very considerable) cannot but be one great means of restoring to the whole mass of air, those salubrious qualities of which it is daily deprived, by the  
*respi-*

*respiration* of animals, the *putrefaction* of bodies, the *combustion* of fuel, and other causes\*.

\* Dr. Priestley has observed, "that the same water, which, if examined immediately, gives only a small quantity of bad air, yields *spontaneously* about ten times the quantity of pure dephlogisticated air, after standing some time exposed to the *sun*." Phil. Trans. 1779, p. 377. An animal will live five times as long in what is called here dephlogisticated air, as it will in common air of the best quality.





## E S S A Y VI.

OF WATER IN A SOLID STATE ; OF  
THE HEAT OF SPRING WATER ;  
AND OF A PROBABLE CAUSE OF  
THE IMPREGNATION OF SULPHU-  
REOUS WATERS.

**T**HE mind of man admits with  
great reluctance, the truth of  
every testimony concerning matters  
of fact, which happen to be repug-  
nant to the uniform experience of  
his senses ; hence the general back-  
wardness

wardness to believe the miracles recorded in the bible; and hence the *Dutchman* who informed the king of *Siam*,\* that water in his country would sometimes, in cold weather, be so hard that men walked upon it, and that it would bear an elephant, if he were there, was esteemed a person unworthy of credit, the king, as Mr. *Locke* relates the story, saying to him, "Hitherto I have believed the strange things you have told me, because I look upon you as a sober man, but now I am sure you lie\*."

*Mahine*, the native of *Borabora*, could scarcely be persuaded, even by the information of his senses, of the reality of the same effect. The appearance of "white stones," as he called

\* *Locke's Essay on the Hum. Und. B. IV. C. XV.*

called hail, which melted in his hand was altogether miraculous to him; and when he had been with difficulty convinced that an extensive field of ice was not common land, he was determined at all events to call it "white land," by way of distinguishing it from all the rest\*.

This determination of the savage was made in the true spirit of philosophy, for ice in small particles is a species of earth, and in solid masses it may be considered as a kind of transparent stone. *The waters*, says Job †, speaking of the effect of frost, *are hid as with a stone*; that is, water conceals its nature, by assuming a stone-like hardness and consistence when it becomes ice. The Russians applied

\* Forster's Voy. Vol. I. p. 530.

† Chap. xxxviii. 30.

applied ice to the same purposes with stone, at the whimsical marriage of *Prince Gallitzen*, in 1739; an house, consisting of two apartments, was built with large blocks of ice, the furniture of the apartments, even to the nuptial bed, was made of ice; and the icy cannon and mortars, which were fired in honour of the day, performed their office more than once without bursting\*.

Ice, however, differs from all other earths and stones, not only in its melting in a much less degree of heat than any of them, but in its being subject to a constant diminution of its weight when exposed to the open air, in the greatest degree of cold. It generally becomes fluid in the 33d degree of heat, as indicated

\* *Manstein's Mem. of Russia.*

rated by Fahrenheit's thermometer;  
 and Mr. Boyle, by exposing in a  
 good balance somewhat less than two  
 ounces of ice to a sharply freezing  
 air, a little before midnight, found  
 it in the morning diminished in  
 weight ten grains \*. It is probable,  
 that this diminution of the weight of  
 ice, is owing to the abrasion of its  
 parts by the action of the air. The  
 particles of air are thought to be  
 larger than the particles of water,  
 and may by their motion acquire  
 force enough to separate the particles  
 of ice; or if this should not be ad-  
 mitted, it must be remembered, that  
 the air always contains a great quan-  
 tity of water, the particles of which,  
 when converted into particles of ice,  
 though in this country they are sel-  
 dom

\* Boyle's Works, Fol. Vol. III. p. 66.

dom large enough to be seen, always make themselves felt by impinging upon our skin: these icy particles when put in motion may abrade the surface of a mass of ice, and cause thereby a constant diminution of its weight. In confirmation of this explanation it may be observed, that ice suffers no loss of its weight in a vessel devoid of air, nor in a close vessel full of air\*. That the icy particles, contained in a freezing atmosphere, should be able to act upon ice, cannot be a matter of difficult conception to those who recollect, that the hardest bodies in nature suffer a diminution of their weight, by the friction of the minute parts of the same kind of bodies; diamond

\* Hamilton on the Ascent of Vapours, p. 71.

mond dust being essentially necessary for the cutting or polishing of diamonds.

That water was diminished in quantity by being frozen, was known to *Hippocrates*; for he expressly says, that if a given quantity of water be frozen, and afterwards thawed, it will not fill the same vessel it would have done before it was frozen \*.

*Pliny* was of the same opinion with *Hippocrates*, and they both of them attribute this diminution of weight to the separation of the more subtile parts of the water during congelation†. The principal cause of the loss of weight, sustained by water when changed into ice, seems to be the incessant

\* *Hippoc. de Aqua.*

† *Plin. Hist. Nat. Lib. II. S. 61. & Lib. XXXI. S. 3.*



incessant action of air upon its surface; it is true, however, that water is, by freezing, deprived of the greatest part of the air with which, in its fluid state, it is ordinarily saturated; and this separation of its air may contribute something towards the diminution of the water's bulk; since water, when saturated with air, is somewhat greater in bulk than when deprived of it.

It is easy to apprehend, that the loss of weight which any given quantity, suppose a cubic foot, of ice will suffer by exposure to the air in a given time, will depend, partly upon the hardness or softness of the ice, partly upon the temperature of the atmosphere, with respect to the degrees of cold and humidity, partly upon the velocity of the wind which  
 brushes

brushes its surface, and probably enough upon the agency of other causes with which we are less acquainted. Some philosophers have estimated, in general terms, the loss of weight sustained by a certain weight of ice; without specifying the magnitude of the ice's surface; others, with more accuracy, have mentioned both the weight and surface of the ice exposed to the air, but then they have either omitted to speak of the ice's consistency, the temperature of the atmosphere, the force and direction of the wind, or they have expressed themselves in very indefinite terms concerning these points, so that we cannot be said to have hitherto gained, from their experiments, any precise information upon the subject. As to the fact itself, the most com-

mon observation is sufficient to ascertain us of its truth. In long continued frosts, the ice formed in ponds, and other small collections of water, is sensibly diminished every day, and often wholly evaporated; and a fall of snow may be seen considerably wasted in a few days, in the severest season.

Nowwithstanding this diminution of weight, to which both ice and snow are subject in the coldest weather, and the thaw which they experience in the hottest, yet some have doubted whether the quantity of congealed water be not an increasing quantity upon the surface of the earth; and have even thought, that the globe of the earth must in process of time resemble an egg, having its diameter from pole to pole, longer than the  
equa-

equatorial diameter, on account of the constant accumulation of frozen water at the two poles.—“ After so many years lapse, it cannot be, I think, but that the diameter of the earth from pole to pole, from the top of the snow at one end of the earth, to the top of it at the other end, is much longer, than in any part under the equator, though at the creation it were, (as I believe) made spherical \*.”

In some mountainous countries, the proportion between the snow which falls at one season of the year, and that which is dissolved in another, approaches so near to an equality, that upon the same spot, the snow may in one year be seen quite through the year, in another, the

\* Childrey's Brit. Bacon, p. 148.

the last speck of it will vanish in a few weeks or days, before a new supply is brought by the approach of winter. In colder climates, the utmost power of the summer sun is not able to melt all the snow which falls in the winter. In ascending mount *Etna*, the *Alps*, or the *Andes*, though the lower parts are found to be rich in vegetation, yet you soon come to a region covered, as it should seem, with everlasting snow : the height at which this region commences, does not admit much variation in the same latitude, but is very different in different latitudes. It begins at the distance of near three miles above the level of the sea, under the equinoctial line ; and at each pole, probably, it is not removed from that level so many hundred feet ;

feet; it is found to be 600 yards nearer to the level of the *sea* at *Teneriffe* than under the equator; and above 1200 yards nearer in *Switzerland* than at *Teneriffe* \*.

Not only the tops of high mountains in every quarter of the globe are covered at all seasons of the year with snow, but the ocean both in the northern and southern hemisphere is, in high latitudes, replete with immense mountains, and extensive plains of

\* *Histo. Nat. des Glaciers Suisse*—The author says, enfin la plupart des Montagnes voisines des poles sont couvertes jusqu'à leur pied de neiges perpetuelles. This observation must not be admitted without restriction, if it be at all true, since in *Greenland*, and in the latitude 79 degrees 44 minutes north, the feet of the mountains are in certain seasons freed from snow. See *Crantz's Hist. of Greenland*, Vol. I. p. 30. and *Phipps's Voy.* p. 52 and 79.

of ice, in the greatest heats of summer ; and hence it has appeared probable to many, that both the snow upon the land, and the ice upon the sea, receive an augmentation every year, from the continued agency of the same cause which first produced them.

A philosopher, well acquainted with the nature of the Alps, expresses himself upon this subject in the following manner : “ One cannot doubt concerning the increase of all the Glaciers of the Alps ; for their very existence is a proof, that in preceding ages the quantity of snow which has fallen during the winter, has exceeded the quantity melted during the summer. Now not only the same cause still subsists, but the cold, occasioned by the mass of ice already formed,

formed, ought to augment it still farther, and thence both more snow ought to fall, and a less quantity of it be melted \*." If this be admitted, the time will undoubtedly come when the sea will be diminished in depth, if not dried up by the conversion of the water, which is daily raised from it, into snow or ice ; and had the world been as old, as some are fond of supposing it to be, we should, probably, have had no water upon its surface at the present day. However, it must be owned, that no argument can be drawn against the antiquity of the world, from this consideration, because there is reason to believe that the ice and snow upon the surface of the earth are not annually increasing in quantity.

\* De Luc de l'Atmosphere, Vol. II. p. 328.



tity. For, besides the heat of the air in summer, there is another cause which tends to prevent an indefinite augmentation of congealed water—the internal heat of the earth. The general heat of the springs of water, situated deep in the bowels of the earth, is 48 degrees ; in mountainous countries, I suspect it to be somewhat less, but sufficient, notwithstanding, for the purpose here mentioned. When the snow, incumbent on any spot of ground, is but thin, it may so far cool the earth, that its internal heat may not be able to dissolve it ; but when the bed is thick enough to protect the earth from the influence of the atmospheric cold, that surface of the snow which is contiguous to the surface of the earth, may, even in the coldest

coldest winters, receive more heat from the earth than it does cold from the atmosphere, and, on that supposition, I see no absurdity in admitting, that it may be dissolved at all seasons of the year.

The fact I believe is certain, that streams of water issue from the bottom of the *Glaciers* in the *Alps*, in the greatest severity of winter; so that whether the internal heat of the earth be admitted, or not, as a cause sufficient to explain the phenomenon, a constant thaw of the ice or snow, which is contiguous to the surface of the earth in the *Alps*, cannot be denied; and this, added to other causes, may render it probable that the quantity of congealed water has its *limit*, even in the coldest climates.

The

The ordinary heat of spring water, which does not feel the vicissitudes of the temperature of the atmosphere, is here said to be 48 degrees of Fahrenheit's thermometer; it may be worth while to add a few remarks on this subject.

In August 1778, when the heat of the air was 72 degrees, I tried, on the same day, the temperature of several springs, reputed cold, in the neighbourhood of *Matlock*; and I found them varying in heat from 50 to 54 degrees. This variation, probably, proceeds from their subterraneous passages being situated at different distances from the surface of the earth, which was then much warmed by the heat of the summer. Or it may proceed from the springs being more or less mixed with the  
water

water which supplies the warm baths, the heat of that water being 68 degrees. There is a subterraneous passage upon the side of the hill near the *new* bath at Matlock, which terminates in a large cavern, situated under one of the fields in the midway between the *new* and the *old* bath; and from this cavern, which is always full, issues the warm water which supplies both the baths; and it may probably ooze out in different directions, and in different quantities, so as to make the neighbouring springs participate more or less of its warmth.

At *Lord Godolphin's* house on *Gogmagog* hills, near *Cambridge*, there is a well, above 230 feet in depth, which is dug through a stratum of chalk; I have frequently examined the heat of the water of this well,

and constantly found it to be 50 degrees. At *Cherry Hinton*, a village situated at the bottom of these hills, there issues from the chalk a very copious spring; the heat of this water, as it bubbles out of the earth, is, at all seasons of the year, 50 degrees. I have tried the heat of some deep wells dug in chalk at *Bury St. Edmund's*, and found it variable from 50 to 52 degrees——“It has been long and generally observed, that as far as the limestone extends, that tract of ground makes the snow that falls on it, thaw or melt sooner than it does on the neighbouring lands\*.” This is Mr. Boyle’s observation concerning some limestone land in Ireland, and he says its truth was confirmed to him by a *Derbyshire*

\* Boyle’s Works, Vol. IV. p. 278.

shire miner, who assured him, that on contiguous districts of land, snow was observed to dissolve much sooner on the soil which covered limestone, than on that which covered freestone. If these observations may be depended on, we may, perhaps, in general infer that the heat of calcareous strata is greater than that of other kinds of strata, and this would furnish a reason for the springs in chalk countries being of the warmth of 50, though the ordinary heat of springs be not above 48 degrees.

In the middle of summer, when the air was 72 degrees hot, I tried the heat of some springs at *Harrowgate* in Yorkshire. Pump-water at the *Granby Inn* 48 degrees.—Old *Spaw* 45 degrees.—*Pewit* or *Tewit* well

well 48 degrees.—Sulphur well 50 degrees. The cold well at *Buxton* examined at the same time of the year was 48 degrees, and the famous Spaw at *Llanrhard'r* in *Denbighshire* was also 48 degrees; St. *Winifred's* well, at *Holywell* in *Flintshire*, was considerably warmer, the thermometer when held in the spring as it rose out of the earth, standing at 54 degrees. I have tried a great many other springs in different parts of Great Britain, and found the heat of most of them to be included between the limits of 48 and 54 degrees, the mean of which is 51. Springs on the sides of high mountains may, probably, participate of the cold which is found to be greater in elevated than in low situations. There is a spring by the side of the  
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turnpike road leading over the high ground called *Otley Shevin* in Yorkshire; I observed the heat of this spring in September, when the air was warmed to 62 degrees, to be not 48, but only 45 degrees. The mean heat of springs near *Edinburgh* is said to be 47, and at *London* 51 degrees \*: this diversity depends, probably, on the different elevations of *London* and *Edinburgh* above the level of the sea.

I have mentioned the *Sulphur* well at *Harrowgate*, according to its usual appellation at that place, without taking upon me to decide the long controverted question, concerning the existence of sulphur in that and other waters of the same kind. *Sulphur* has been long esteemed a

VOL. III.

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\* *Philos. Trans.* 1775, p. 460.



mineral body very common to be met with in waters; and all those waters which have a strong fetid smell, resembling that of a foul gun, have been esteemed to be more or less impregnated with sulphur. However, Dr. *Hoffman* seems to doubt much of its existence in the greater number of such waters; and Dr. *Lucas* has affirmed, that it is not to be found in the form of sulphur in any water whatever; not even in that of *Aix-la-Chapelle*, where a true and perfect sulphur is found on the upper parts of the conduits through which the water passes; for he says, that, strictly speaking, these waters do not contain sulphur substantially dissolved in them, but are impregnated with a phlogiston and an acid, the principles of sulphur; which being

ing in a volatile state, are sublimed, meet on the surface of the conduits, and there unite into a true and perfect sulphur, which did not naturally exist in the water\*." The author, from whom I have made this extract, informs us, that Dr. *Rutty* maintains the existence of sulphur in mineral waters; and that both Dr. *Shaw* and Dr. *Short* found sulphur in Harrowgate water. Notwithstanding the testimony of such eminent physicians, the more recent opinion of a physician, whom Dr. *Monro* consulted on the subject in 1768, is against the existence of sulphur in such waters. "I have taken particular notice of every appearance of the Harrowgate waters, and must

\* *Monro on Mineral Waters*, Vol. I. p. 30 and 196.

own I never observed any appearance of sulphur floating in them, nor any scum at the top of the well; neither could I meet with any person in that quarter, who remembered the appearance of real sulphur sublimed, upon taking up the stones at the bottom of the well, as mentioned by Dr. *Neal*\*.—I beg leave to add my own observation on the subject, which I made in 1780. The water in the well rises into a circular stone basin; a whitish crust adheres to the stone, where it is contiguous to the surface of the water; I scraped off a portion of this crust, and putting it on a hot iron, I found that it burned with the *flame* and *smell* of *sulphur*. I do not think that this experiment absolutely warrants us to  
con-

\* *Monro on Mineral Waters*, Vol. I. p. 196.

conclude, that *actual sulphur* is contained in this and other waters generally denominated sulphureous; we justly infer from it, that something is sublimed from the water, which either of itself is sulphur, or which in conjunction with the air, or some other principle, constitutes sulphur.

The prosecution of this subject would lead to speculations too abstruse for my design; the following experiment, however, which I have frequently made, will, I hope, throw no inconsiderable light on the cause of the impregnation of sulphureous waters in general.

The acid of vitriol does not act upon the common Derbyshire lead ore, except when it is assisted by heat, it then dissolves it, and a great

escape of air is observed: I made this air, as it was discharged from the ore, pass through a high-bended tube into a bottle full of pump water: the water, in a very little time, acquired the *fetid smell* of Harrogate water,—its taste was the same as that of such sulphureous waters as contain no salt,—it was perfectly *transparent*, but in the course of 24 hours it became *cloudy*, and lost most of its smell,—it did not suffer any *precipitation* by the addition of the acid of vitriol,—*silver* was *blackened* both by being put into this water, and by being exposed to the vapour which arose from it; from all these circumstances, it may properly enough, I think, be called an *artificial sulphureous water*.

I have observed the same phenomena

mena when, instead of lead ore, I used *black jack*; and I remember that once having placed a bottle, containing black jack and acid of vitriol, so that its neck leaned against a plaistered wall, I observed some days afterwards, that the wall was stained, to the distance of above a foot from the mouth of the bottle, of a purple colour, resembling the purple sediment often found in sulphureous wells.

Air of the kind here spoken of, may be separated from other substances, as well as from lead ore and black jack, and by other means, as well as by the acid of vitriol; and it seems very probable, that the waters usually called sulphureous, are impregnated with this kind of air, which has been separated, in the bowels

bowels of the earth, from particular minerals, especially fulphureous ones. It has been remarked of Harrowgate water, that as it springs up it is clear and *sparkling*, and throws up a quantity of *air bubbles*.

During the process of impregnating water with air, by dissolving lead ore in the acid of vitriol, a part of the glass tube was coated with a thin pellicle of sulphur, which had accompanied the air in its ascent: May not the sulphur sublimed from Harrowgate water, have accompanied the air which gives it its smell? Is it certain that *this kind of air* does not consist of attenuated parts of sulphur, which have acquired an elastic force, and which cannot be condensed in water? Or is it not more probable, that this kind of air is one  
of

of the constituent parts of sulphur, than sulphur itself? Does this air, and the inflammable air separable from some metallic substances, by solution in acids, consist of *oleaginous* particles in an elastic state?

If the reader wishes to impregnate common water with the sulphureous properties of Harrowgate water, he may do it in the following simple manner:—Into an apothecary's vial, holding four or five ounces, put some pounded lead ore, and pour upon it some acid of vitriol (there is no occasion to be solicitous about the proportions of the lead ore and acid, for if there be more or less ore than the acid can dissolve, still air enough for the purpose will be discharged); wrap a few folds of wet linen round one end of a bended  
6 tube;



tube, insert this end into the neck of the vial so closely, that no air may pass out of the vial except through the tube; the end of the tube should be at some distance from the surface of the acid. Put the other end of the tube into a bottle full of water, then, by setting the vial on the hot bar of a grate, or by some other means, heat the acid, and as soon as it is heated, it will begin to act on the lead ore, and a great quantity of air will be discharged, which will pass through the tube into the water in the bottle, and in a few minutes the water will be strongly impregnated with the sulphureous properties of Harrowgate water. Besides its sulphureous impregnation, Harrowgate water contains sea salt; and most other sulphureous waters contain

contain some salt or other, so that to make a complete imitation of them, the salts which they severally hold should be added, in due proportion, to the water impregnated with the air here spoken of.

Though I am greatly disposed to believe, that sulphureous waters are impregnated with their peculiar smell and taste, after the manner I have described; yet, to assist the reader's conjectures concerning the origin of this impregnation, I will mention another way in which it may be supposed to arise, and which will account for the saline taste as well as the smell of the water.

I know not whether any species of maritime plants, containing sea salt, will impregnate water with a sulphureous smell by means of *putrefaction*;

*faction*; nor whether all of them will do it by means of *combustion*, but that one of them will do it I can have no doubt: I allude to the *bladder fucus* or *sea wrack*, which is burned on our coasts for the making of *kelp*. It has been mentioned before \*, that sea wrack, when burned to a black coal, will yield, by being boiled in water, a great quantity of common salt; and I would now remark, that the water extracts from the black ashes, not only a great quantity of common salt, but *something* else also, by which, without losing its transparency, it acquires both the finell and sulphureous taste of Harrowgate water; and by which it is enabled, like that water, to blacken silver and white paint.

That

\* Vol. I. p. 137.

That *something* I am sensible may be what chemists call *liver of sulphur*, or an union of sulphur with fixed alkali, and it would not be difficult to explain its formation during the combustion of the sea wrack; no sulphur however can be precipitated from the water by the acid of vitriol, though that acid turns it, as is the case with Harrowgate water, a little cloudy. The air extracted from iron by the acid of sea salt, impregnates water with a smell somewhat resembling that of Harrowgate water, but its difference both from the natural and the artificial sulphureous waters, may be easily distinguished, especially after the water has stood a few hours exposed to the air.



## ESSAY VII. \*

### OF DERBYSHIRE LEAD ORE.

**L** E A D ore, as dug out of the mine, is generally much mixed with spar, limestone, and other substances, bulk for bulk, lighter than the ore itself. It undergoes various dressings before it becomes a merchantable commodity, the general tendency of which is to free it, as much as possible, from every heterogeneous impurity.

Suppose

\* The substance of this Essay was printed in the Philos. Transf. 1768.

Suppose that a cubic foot of lead ore, which contained no spar or other extraneous matter, would weigh 7800 ounces, and that a cubic foot of spar, which contained no lead ore or other foreign substance, would weigh 2700 ounces, then would a mixture, consisting of a cubic foot of pure lead ore, and a cubic foot of pure spar, weigh 10500 ounces, and one cubic foot of such a mixture would weigh 5250 ounces. It is obvious that, according to the different proportions in which the particular kinds of spar and lead ore here assumed, are supposed to be mixed together, a cubic foot of the mixture will have different weights, the limits of which are on the one hand 7800, and on the other 2700 ounces; it never can weigh so little as 2700 ounces, for  
then

then it would consist intirely of spar without any lead ore; nor can it ever weigh so much as 7800 ounces, for then it would consist intirely of lead ore without any spar.

From this view of the matter it is evident, that the purchasing of lead ore by the measure, which is the general, though not the universal custom in *Derlyshire*, is a mode liable to some exception; since a dish, containing any definite measure, must have different weights according as the ore with which it is filled is more or less free from spar. And it is scarce possible, by repeated dressings, to separate all the spar from an ore, or equal portions of it from equal portions of ore.

There is a diversity, however, in the weights of equal measures of lead



ore which, probably, does not arise from sparry or other heterogeneous accretions, but from the nature of the ore itself. I have carefully calculated the weight of a cubic foot of many of the Derbyshire lead ores; the weight of a cubic foot of the lightest which I met with was 7051 ounces, and the weight of a cubic foot of the heaviest was 7786 ounces; the difference amounting to between a ninth and a tenth part of the weight of the lightest. There are, probably, other ores of lead, the weights of equal bulks of which differ more than these here mentioned; but the difference between these is sufficient to shew the great uncertainty of purchasing lead ore by the measure, since ten dishes of one sort of ore may not weigh more than nine dishes  
of

of another sort, though both the sorts are equally well dressed.

Lead ore is not always of the same goodness in the same mine, nor even in the same part of the same mine; and, what is more remarkable, the different parts of the same lump of ore have in equal bulks different weights. I could not easily have believed this, unless a variety of experiments had convinced me of the fact.

They were employed lately at *Holywell* in smelting a lead ore from the *Ile of Man*; the ore was rich in silver. A lump of this ore, weighing about ten ounces, was broken into several pieces, and such of the pieces were selected as appeared to the eye to be wholly pure. I estimated the weight of a cubic foot of six of those pieces,



and found that a cubic foot of the lightest kind would have weighed 6565 ounces, and a cubic foot of the heaviest kind would have weighed 7636 ounces. Supposing the weight of a cubic foot of water, to be denoted by 1000, the mean weight of a cubic foot of the six different pieces of this ore, may be expressed by 7115 avoirdupoise ounces.

A very pure specimen of tessellated lead ore, from a mine near *Asb-over* in *Derbyshire*, was broken into six pieces, weighing near one ounce each. A cubic foot of the lightest of these pieces would have weighed 7326 ounces, and a cubic foot of the heaviest would have weighed 7786 ounces. The mean weight of a cubic foot of the six pieces was 7566.

At

At the same mine they frequently meet with small quantities of steel-grained lead ore. Six different pieces of the same lump of this kind of ore were chosen, each of which appeared quite free from spar and every other impurity. A cubic foot of the lightest of these pieces would have weighed 7188 ounces, and a cubic foot of the heaviest would have weighed 7442 ounces. The mean weight of a cubic foot of the six pieces was 7342.

Other lumps of ore from different mines, were respectively broken into different pieces, and scarcely any two equal pieces of the same lump were observed to agree in weight. This diversity in the weights of equal bulks of the several pieces of the same lump of ore may be owing,

either to the different proportions in which the constituent parts of the ore are combined in the several pieces; or to the different quantities of extraneous substances imperceptibly mixed with them; or, which seems most probable, to a diversity in the size or configuration of their pores.

But be the cause of this diversity what it may, the fact, I believe, is certain, and by no means singular; for not to mention the varieties observable in the weights of equal bulks of different pieces of roll brimstone, of corrosive sublimate, of cast steel, and other factitious substances, the natural spars generally found along with lead ore are subject to a similar diversity, though nor, perhaps, in an equal degree.

A piece of *rhomboidal*, otherways  
 I called

called *refracting* or *lantern spar*, was broken into four smaller pieces, the weights of a cubic foot of each of which were 2675, 2687, 2715, 2723; the medium of the four is 2700 ounces. Mr. Cotes fixes the weight of a cubic foot of Iceland crystal at 2720, and *Wallerius* fixes it at 2700 ounces.

The weights of a cubic foot of four pieces of the same lump of *cubical spar* were 3204, 3218, 3222, 3231; the medium of the four is 3219 ounces.—Most of the spars met with in *Derbyshire* are either *rhomboidal* or *cubical*; they are easily distinguished from each other by a view of their shape, when their angles can be discerned; and when the shape cannot be easily seen, the nature of the spar may be ascertained

by touching it with an acid; the rhomboidal spar always effervescing with an acid; and the cubical resisting its action. The lead smelters make great use of the cubical spar as a *flux* for such lead ores as do not readily melt: it is curious to see its effect; a few shovels full of it, thrown upon a heap of red hot ore, immediately melting down the ore into a liquid, though the longest continuation of the same degree of heat, without the addition of the spar, would not have been sufficient for the purpose.

Six ounces of fine tessellated lead ore were put into a crucible and exposed, at first, to a gentle, and afterwards to a strong fire: the ore grew red, and emitted fumes which smelled of sulphur; at length it melted,  
and

and the fumes became very copious; they were accompanied with a yellowish flame upon the surface of the melted ore, and when collected had a whitish appearance. The crucible after the ore had continued a full hour in perfect fusion, was taken from the fire, and when it was cold it was broken. The mass which it contained weighed five ounces and an half; there was no scoria observable on its surface, nor were any particles of metal formed; it was still an ore of lead.

The mass remaining from the last experiment was put into a fresh crucible, and exposed to a strong melting heat; the fumes which arose from it seemed to be heavy; they brooded over the surface of the melted mass in undulating flames, which



which now and then appeared like burning zinc \*. The lead was now formed, and many particles of it were sublimed to at least six inches above the surface of the liquid in the crucible. After letting the crucible continue two hours in this state, I poured out its contents, and found them consisting partly of lead, partly of lead ore, and partly of a very minute portion of brownish scoria. I repeated this experiment with the same success.

These experiments prove, that some substance or other is contained in lead ore, which must be dispersed before the ore can be formed into lead; and they shew too, that it requires a considerable time to effect

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\* It may deserve to be inquired whether zinc may not be contained in lead, iron, and other ores, more frequently than is supposed.

the dispersion of this substance, since six ounces of ore, though kept three hours or more in complete fusion, were not wholly brought into the form of lead; they instruct us also to believe that the lead in this kind of ore is in its metallic state, as the ore was changed into lead without the addition of any substance containing the inflammable principle; and, lastly, they render it probable, that the fumes arising from melted ore, carry off with them no inconsiderable portion of the lead itself. At the great smelting houses in Derbyshire, they put a ton of ore at a time into the furnace, and work it off in eight hours; the ore might be wholly melted in one hour, but the lead, perhaps, is not formed in the greatest possible quantity in eight hours.

Some

Some fine tessellated lead ore from Derbyshire, was pounded into small lumps, each about the size of a pea, and carefully picked from spar and other impurities. Sixteen ounces of this ore, thus previously cleansed, were distilled in an earthen retort; as soon as the ore felt the fire, the stopple of the quilled receiver had a strong smell, resembling that of the inflammable air, separable from some metals by solution in acids; soon after a small portion of a liquid came over into the receiver; the fire was then raised till the retort was of a white heat, when a black matter began to be sublimed into the neck of the retort; the operation was then discontinued. This experiment was undertaken with a view of seeing whe-

whether sulphur could be separated from lead ore, as it may be from some species of the pyrites, by distillation, and it appears from the issue of the experiment that it cannot, at least in the degree of heat which is requisite for subliming the ore. Upon breaking the retort, I found that the ore had been melted during the operation, for there was a consistent cake of ore of the figure of the bottom of the retort; the weight of this cake was fifteen ounces and an half, the weight of the liquid in the receiver, and of the black matter which had been sublimed, did not together amount to one quarter of an ounce, so that a quarter of an ounce or more had been dispersed, probably in the form of air, or some elastic fluid. The ore by this process

cess had lost one thirty-second part of its weight. The liquid did not effervesce with either acids or alkalis; nor did it produce any change in the colour of blue paper; yet I am certain, from experiment, that one drop of oil of vitriol, though diluted with two ounces of water, would have produced a sensible redness on the blue paper which I used. The liquid, notwithstanding, had an acid taste, and a pungent smell, resembling that of the volatile vitriolic acid. The black matter which had been sublimed into the neck of the retort, was examined with a microscope, and it appeared to be pure lead ore. The melted ore which was found at the bottom of the retort, had not any appearance of scoria, or of lead, upon its surface.

Some

Some phenomena attending this experiment deserved, I thought, a further investigation. I therefore distilled another 16 ounces of ore, but with a fire stronger and continued for a longer time than in the preceding experiment: the quantity of liquid was much the same, there was a smell of sulphur, and, perhaps, to the amount of half a grain of sulphur was found in the receiver; the ore was in this experiment sublimed into the neck of the retort to the thickness of one fourth of an inch. There was found, as before, a cake of melted ore at the bottom of the retort, but no sensible portion of either *lead* or *scoria*\*; so that we may  
safely

\* I have said no sensible portion; there was, however, an appearance of scoria adhering to the side, and an appearance of lead adhering

safely conclude that lead ore cannot be decomposed by the strongest fires in close vessels, but that it may be sublimed in them. The ore had lost near an ounce of its weight.

Though the experiment is sufficiently troublesome, I was not deterred from making it once more; for I wanted to see whether lead ore could be wholly sublimed; as I thought that philosophers might thereby form some conjectures of the efficacy of subterraneous fires in subliming

adhering to the bottom of the retort; but the quantity of each was exceedingly small, and they were both, probably, produced from that minute decomposition of the ore which produced the sulphur, and which would not, I think, have taken place in any degree, had there been no communication with the external air; but the orifice of the quilled receiver was not always closely stopped during the distillation.

in lead ores, and, perhaps, ores of other metallic substances. The event of this third experiment was perfectly correspondent to that of the two former, with respect to the production of liquid, and the separation of air, which was caught in a bladder, but was not found to be inflammable: the lead ore too was so plentifully sublimed into the neck of the retort, that it quite plugged it up for above three inches in length. Upon discontinuing the fire which had been raised to a degree of heat exceedingly great, I found the retort was cracked, and that the cake at its bottom was very different from what was found at the bottom of the other retorts, which had stood the fire without cracking; for this cake was covered with a black glassy sc-



ria  $\frac{1}{4}$  of an inch in thickness, and the ore which laid under it, was in part changed into *lead*, and the whole of the ore did not weigh quite ten ounces, so that above six ounces had been lost by escaping through the crack. By a communication with the air through the crack, the ore was decomposed, and thus both *lead* and *scoria* were formed, which in the other experiments, for want of such a decomposition, could not be formed. There was a thin coat of sulphur also which lined the inside of the receiver, and this sulphur, probably, arose from the decomposition of the ore, since none, or next to none, was observed in the other distillations of the ore. I found that the weight of a cubic foot of the ore, which had been sublimed into

the neck of the retort, was 7500 ounces; which sufficiently agrees with the weight I had before ascertained of this kind of ore. A cubic foot of the black glassy scoria weighed 3333 ounces; and the metallic cake which laid under it, and which consisted partly of lead, and principally of ore not quite changed into lead, gave 8738 ounces to the cubic foot.

Finding that sulphur could not be separated from lead ore by distilling it in close vessels without addition, and yet being much disposed to think that it contained a considerable portion of sulphur, I first thought of distilling it with charcoal dust, iron filings, sand and other additions; but recollecting that sulphur might be separated from antimony

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by

by solution in acids, I thought it not improbable, that it might be separated from lead ore by the same means, and the success of the following experiment abundantly justified the conjecture.

Upon ten ounces of lead ore, cleansed as in the preceding experiments, I poured five ounces of the strongest fuming spirits of nitre ; this strong acid not seeming to act upon the ore, I diluted it with five ounces of water ; a violent ebullition, accompanied with red fumes, immediately took place ; the solution of the ore in this *menstruum* became manifest, and when it was finished, there remained floating upon the surface of the *menstruum* a cake of fine yellow sulphur, perfectly resembling common sulphur.

I re-

I repeated this experiment a great many times, in order to ascertain the quantity of sulphur contained in lead ore, and separable therefrom by solution in acid of nitre. The results of different experiments were seldom the same; the matter separable from the ore by solution, after being repeatedly washed in large quantities of hot water, in order to free it from every saline admixture, sometimes amounted to more, sometimes to less than one-third of the weight of the ore. This matter may, for the sake of distinction, be called crude sulphur. Its apparent purity might induce a belief that it contained no heterogeneous mixture, yet the following experiments shew how much we should be deceived in forming

such a conjecture, and how rightly it is denominated crude sulphur.

From one hundred and twenty parts, by weight, of lead ore, I obtained, by solution in acid of nitre, subsequent washing in hot water, and drying by a gentle fire, forty parts of a substance which looked like sulphur: these forty parts were put on a red-hot iron, the sulphur was made manifest by a blue flame and pungent smell. When the flame went out there remained upon the iron unconsumed, twenty-six parts of a greyish *calx*; the weight of the sulphur which was consumed must therefore have amounted to fourteen parts, or between one eighth and one ninth part of the weight of the ore. It has been observed, that the weight of the matter, separable from lead ore  
by

by solution in acid of nitre, sometimes exceeded and sometimes fell short of, one third part of the weight of the ore; this variety, as far as I have been able to observe, does not extend to the quantity of sulphur contained in a given quantity of ore, it depends upon the quantity of *calx* remaining after the burning of the sulphur. Different lead ores will doubtless contain different quantities of sulphur; but that the sulphur contained in the lead ore which I examined, constitutes between one eighth and one ninth part of the weight of the ore, is a conclusion upon which, from a variety of experiments, I am disposed to rely.

There are said to be annually smelted in *Derbyshire* about ten thousand tons

of lead ore\*; now if means could be invented (which I think very possible) of saving the sulphur contained in ten thousand tons of ore, supposing that the ore should only yield one tenth of its weight of sulphur, though it unquestionably contains more, *Derbyshire* alone would furnish annually one thousand tons of sulphur, the value of which would annually be about fifteen thousand pounds. I mention this circumstance thus publicly, in hopes that the lead smelters may be induced to prosecute the subject. If the sulphur contained in the lead ore could be collected, it would not only be a lucrative business to the smelters, but a great saving to the nation. We at present

\* This estimate is, I have reason to think, too high.

present import the sulphur we use, and the consumption of this commodity is exceeding great, in the making of gunpowder, in forming the mixture for covering the bottom and sides of ships\*, and in a great variety of arts. The smelters need not be apprehensive lest the quality of the ore should be injured by extracting the sulphur. Eighteen hundred weight of ore, from which the sulphur has been extracted, will certainly yield as much lead as twenty hundred weight of ore, from which the sulphur has not been extracted, and it will, probably, yield more. Arsenic is ex-  
tracted

\* This mixture is made of one part of tallow, of one part of brimstone, and of three parts nearly of rosin. The tallow and rosin are melted together, and the brimstone is stirred into them; 140 pounds of brimstone is enough for a vessel of 140 tons.



tracted from a particular ore in Saxony, by roasting the ore in a furnace, which has a long horizontal chimney; the chimney is large, has many windings and angles, that the arsenic vapour which arises from the ore may be the more easily condensed: the arsenic attaches itself like soot to the chimney, and is from time to time swept out. It is very probable, that by some such contrivance the sulphur contained in lead ore might be collected. The smelters call every thing sulphur which is volatilized during the roasting or fluxing of an ore; but none of those with whom I have conversed, had any notion that common sulphur could be separated from lead ore.

The greyish calx which remained  
upon

upon the iron after the sulphur was consumed, was put upon a piece of lighted charcoal; the heat of the charcoal being quickened by blowing upon it, a great number of globules of lead were formed upon its surface. From hence it appears, that this calx is not an unmetallic earth contained in the ore, which the acid of nitre could not dissolve; but a calx of lead, probably produced by the violent action of the acid, and which, by the addition of phlogiston, may be exhibited in its metallic form. The quantity of this calx depends much upon the action of the acid upon the ore; if that action is violent, the calx is in greater abundance than if it be moderate; and I am not certain whether the experiment might not be so managed,

managed, that there would be little or no calx remaining; that is, a given quantity of ore might be so dissolved in the acid of nitre, that nothing would remain undissolved except the sulphur. But I have not yet perfectly satisfied myself as to the constituent parts of lead ore. I am certain that it contains *lead*, and *sulphur*, a *liquid*, and *air*: of the existence of the three first there can be no doubt, from what has been said, and the air is rendered beautifully apparent by the following experiment.

Let some lead ore be reduced into a fine powder, put it into a narrow-bottomed ale glass, fill the glass three parts with water, drop into the water a portion of the strong acid of nitre, you may judge of the requisite

site quantity by seeing the solution  
 commence, and you will observe the  
 ore universally covered with bubbles  
 of air, these will buoy the ore up  
 in large tufts to the surface, and the  
 air will continue to be separated  
 from the ore till the acid becomes  
 saturated with the lead. The salt  
 arising from the union of the nitrous  
 acid to the lead often appears cry-  
 stallized upon the surface of the  
 menstruum in this experiment; and  
 if, when the menstruum is in that  
 state, a little fresh acid be added, the  
 salt instantly crystallizes and falls  
 down to the bottom of the glass, the  
 acid having absorbed the water which  
 held it in solution. When lead is  
 dissolved in the manner here men-  
 tioned, by a very diluted acid of ni-  
 tre, there is no appearance of sul-  
 phur

phur upon the surface of the menstruum, there is found at its bottom a black matter, which is the sulphur.

But though lead, and sulphur, a liquid, and air \*, are unquestionably constituent parts of lead ore, I do not take upon me to say, that they are the only constituent parts: it is well known, that during the smelting of lead ore, a third part or more of its weight is some how or other lost, since from one and twenty hundred weight of ore, they seldom obtain above fourteen hundred weight of lead. What is lost partly consists of a scoria which floats upon the surface of the lead during the operation of smelting, and partly of what  
is

\* I have separated inflammable air from lead ore, by dissolving it in the acid of sea salt.

is sublimed up the chimney and dissipated in the air. The scoria, I apprehend, would be very little, even from a ton of ore, if the ore was quite free from spar: it is the spar which is mixed with the ore that constitutes the main portion of the scoria \*. I have in my possession a solid mass of scoria, which accidentally flowed out from a smelting furnace, and which in colour and consistency perfectly resembles grey lime stone; it receives a polish as fine as marble, and it might perhaps with advantage be cast into moulds for paving stones, chimney pieces, and other  
mat-

\* The spar without question augments the quantity of the scoria, yet the lead ore, which appears to the eye to be quite free from spar, yields a considerable portion of a black glassy scoria, when urged with a sufficient fire.

matters. It arises from the spar mixed with the ore, and, by the addition of cubical spar to the ore during its fusion, its quantity might be increased at no great expence, in any proportion. That part of the ore which is sublimed and dispersed in the air, consists partly of the sulphur which is decomposed, and partly of lead; this sublimed lead attaches itself in part to the sides of the chimney of the smelting furnace; the rest of it flies up into the air, from whence it falls upon the ground, poisoning the water and herbage upon which it settles. This sublimed lead might be collected either by making it meet with water, or with the vapour of water, during its ascent, or by making it pass through an horizontal chimney of a sufficient length.

It is not easy to determine with precision the quantity of this sublimed lead ; a general guess, however, may throw some light upon the subject. They usually at a smelting house work off three tons, or sixty hundred weight, of lead ore every twenty-four hours ; the sulphur contained in sixty hundred weight of ore, we will suppose to be seven hundred weight, and the lead to be forty hundred weight ; the air, liquid, scoria, and sublimed lead must together, upon this supposition, amount to thirteen hundred weight ; now, admitting three hundred weight of the thirteen to be sublimed lead, it is evident that, could it be collected, there would be an annual saving at each smelting house of above fifty tons, which, supposing it to be



worth four pounds *per* ton, would amount to above two hundred pounds a year. The price, if not the quantity of lead sublimate, here assumed, is, probably, below the truth ; but my end is answered in giving this hint to persons engaged in the smelting business.

The following experiments, though upon a different subject, may not be unacceptable to the lovers of chemistry, as I do not remember to have any where met with them.

It is commonly known, that the surface of melted lead becomes covered with a pellicle of various colours. I undertook some experiments in the course of last winter, with a view to ascertain the order in which the colours succeeded each other. The lead which lines the  
boxes

boxes in which tea is imported from China happening to be at hand, some of it was melted in an iron ladle ; but I was much surpris'd to find that its surface, though it was presently covered with a dusky pellicle, did not exhibit any colours. Imagining that the heat was not sufficiently strong to render the colours visible, the fire was urged till the ladle became red hot, the calcined pellicle upon the surface of the lead was red hot also, but it was still without colour. The same parcel of lead was boiled in a crucible for a considerable time ; during the boiling a copious steam was discharged, and the surface of the lead, as is usual, became covered with a half vitrified scoria. The lead which remained unvitrified was then examined, and it

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had

had acquired the property of forming a succession of coloured pellicles, during the whole time of continuing in a state of fusion.

Another portion of the same kind of lead was exposed to a strong calcining heat for a long time; the part which remained uncalcined did, at length, acquire the property of exhibiting colours sufficiently vivid.

These experiments induced me to conclude, that the Chinese lead was mixed with some substance from which it was necessary to free it either by sublimation or calcination, before it would exhibit its colours. It would be useless to mention all the experiments which I made before I discovered the heterogeneous substance with which I supposed the Chinese lead was mixed. At last I  
hit

hit upon one which seems fully sufficient to explain the phenomenon. Into a ladle full of melted Derbyshire lead, which manifested a succession of the most vivid colours, I put a small portion of tin, and observed, that as soon as the tin was melted, and mixed with the lead, no more colours were to be seen. I do not know, precisely the smallest possible quantity of tin, which will be sufficient to deprive a given quantity of lead of its property of forming coloured pellicles, but I have reason to believe that it does not exceed one five thousandth part of the weight of the lead. .

Derbyshire lead, which has lost its property of exhibiting colours by being mixed with tin, acquires it again, as is mentioned of the Chinese

lead, by being exposed to a calcining heat for a sufficient time ; the tin, it is supposed, being separated from the lead by calcination, before all the lead is reduced to a calx.

Some calcined Chinese lead was *reduced* to its metallic form by burning some tallow over it. The *reduced lead* gave, when melted, coloured pellicles ; the calx of tin, which we suppose to have been mixed with the calcined lead, not being so easily reducible as that of lead.

I find that *zinc* is another metallic substance which has the same property as tin with respect to the depriving lead of its power of forming coloured pellicles ; but it does not, I think, possess this power in so eminent a degree as tin. I put small portions of *bismuth* also into melted lead,

lead, but the lead still retained its quality of forming colours. I melted together some silver and lead, but the lead did not thereby lose its power of forming colours. A little tin added to a mixture of lead and bismuth, or to a mixture of silver and lead, immediately takes away from the respective mixtures the faculty of forming coloured pellicles.

This quality of tin has hitherto, as far as I know, been unobserved; but every new fact, relative to the actions of bodies one upon another, ought to be recorded. The change, produced in lead by the admixture of a small portion of tin, is much felt by the plumbers, as it makes the metal so hard and harsh, that it is not without difficulty they can cast it into sheet lead. If their old lead

does not work so willingly, nor exhibit colours so readily, as new lead, they may refer the difference to the small quantity of tin contained in the solder, from which old lead can seldom be thoroughly freed.

With respect to the order in which the colours succeed one another upon the surface of melted lead, it seems to be the following one ; *yellow, purple, blue,—yellow, purple, green,—pink, green,—pink, green.* Upon exhibiting the bright surface of melted lead to the air, I have often observed these ten changes to follow one another in a more or less rapid succession, according to the degree of heat prevailing in the lead. If the heat is but small, the succession stops before it has gone through all the changes : but with the greatest heat  
I did

I did not observe any further variation. All the colours are very vivid, and each seems to go through all the shades belonging to it before it is changed into the next in order.

The formation of these colours may be explained from what has been advanced by Sir *Isaac Newton*, and illustrated by the very ingenious experiments of Mr. *Delaval*, relative to the size of the particles constituting coloured bodies.





## ESSAY VIII.

OF THE SMELTING OF LEAD ORE,  
AS PRACTISED IN DERBYSHIRE.

**T**HERE is a certain standard of perfection in the exercise of every art, which is not always well understood; and after men do sufficiently comprehend it, many ages often pass away before they are fortunate or ingenious enough to attain it. To extract the greatest possible quantity

quantity of metal, from any particular kind, and any definite quantity of ore, is a problem of great importance, whether it be considered in a philosophical or a commercial light; yet he who should apply himself to the solution of it, with an expectation of being useful to mankind, must take into consideration another circumstance, of as much importance as the quantity of metal to be extracted,—the expence attending the process. For it is obvious, that a great quantity of metal extracted at a great expence, may not produce so much clear profit, as a less quantity procured at an easier rate; there is a beneficial limit between the quantity to be obtained, and the expence attending the operation, which nothing but experience can ascertain.

It has been proved, by experiments made in *France*,\* that lead ore, when smelted by a fire made of wood, yielded one tenth more lead, than in the ordinary method of smelting by means of pitcoal; yet pitcoal is so much cheaper than wood, in Derbyshire, and most other parts of Great Britain, that the loss of a tenth of the lead is, probably, more than compensated, by the use of pitcoal instead of wood or charcoal. It is possible, perhaps, even with the use of pitcoal, by an alteration in the process of smelting, to extract from every twenty tons of ore, one ton more of lead than is any where extracted at present; but whether the price of one ton of lead, would be more

\* *Essais des Mines*, par M. Hellot, Vol. II.  
p. 114.

more than sufficient to defray the extraordinary expence attending the alteration of the process, must be left to the decision of those who are interested in the success of such inquiries.

The art of smelting the ores of all metallic substances, was, probably, at first very imperfect in every part of the world; and this doubtless has been a reason, why the use of iron has every where been of a more recent date, than that of the other metals, since it requires the application of a much stronger fire to smelt the ores of iron, than those of any other metal.

We have no certain account when, or by whom, the several metals were discovered; *Wallerius* says, that, as far as he knew, *Pliny* was the first  
who

who enumerated the *six metals* : \* Pliny may, probably, be the first Natural Historian who mentioned them, but they were certainly known long before the age of Pliny, and were mentioned both by *Homer*, and by an author far more ancient than *Homer*—*Moses*.—" Only the *gold*, and the *silver*, the *brass* (*copper*), the *iron*, the *tin*, and the *lead*, every thing that may abide the fire, ye shall make it go through the fire, and it shall be clean." † From this testimony we are certain that all the metals were known, at least in the country of the *Midianites*, above 1450 years before the birth of Christ, or near 900 years after

\* — Prius (scil. Plinius) quantum mihi constat, sex metallâ enumeravit. *Waller, de Syf. Minera. p. 16.*

† Numb. xxxi. 22.

after the deluge. When I say all the metals, I must be understood to mean, all those which were anciently known; for *platina*, the seventh metal, has been but recently discovered, and is not yet brought into general use; and *quicksilver* or *mercury* is not admitted by mineralogists into the class of metals; though it has a good right to be admitted, since in a sufficient degree of cold, it possesses the great characteristic property of a *metal*, as distinguished from a *semi-metal*—*malleability*. This property of malleability, as constituting the criterion by which metals differ from semi-metals, is not over rigidly to be insisted on, since iron, when first fluxed from its ore, or when converted into steel, and hardened by being suddenly immersed when red hot

hot in water, is less malleable than zinc, which is always classed amongst the semimetals.

It has been contended, that copper was one of the first metals which was used as money, and that gold and silver were, in very remote ages, of little account in that view. In many instances the greatness of the *Roman* name has made us forget the æra when that people began to be distinguished in history, and induced us to consider their customs, as the first which prevailed amongst mankind. It is granted, that *Servius Tullius* first coined copper, and that the Romans used no other currency till the four hundredth and eighty-fifth year of their city \*, when silver began to be coined; but from this

\* Plin. Hist. Nat. Lib. XXXIII. S. 13.



concession, no argument can be deduced for the sole use of copper as a currency, in the first ages of the world. We know, from undoubted authority, that silver was used in commerce, at least eleven hundred years before even the foundation of Rome.— *And Abraham weighed to Ephron, the silver which he had named in the audience of the sons of Heth, four hundred shekels of silver, current money with the merchant* \*. About 60 years before Abraham paid this sum for a piece of land in *Canaan*, he is said, upon his return from *Egypt*, to have been rich, not in copper and iron, but in silver and gold †.

Iron and copper were certainly known before the deluge; and it is probable, that all the other metals,  
every

\* Gen. xxiii. 16.    † Gen. xiii. 2.

every one of which is more easily extracted from its ore than iron and copper are from theirs, were known also to the antediluvians; we have proof, however, that in the time of Abraham, gold and silver were esteemed, as they are at present, precious metals; and hence it seems reasonable enough to conclude, that *Noah* was able to instruct his descendants in the art of smelting metallic ores: but, though this be admitted, we need not be surprised at the ignorance of many barbarous nations in this particular. For the various colonies which, either by compulsion or choice, quitted the plains of *Asia*, in search of settlements, may not always have had in their company men who had been instructed in the art of smelting; and those who

did understand it, when the colony first migrated, may, in many instances, have died before any ores were discovered, upon which they might have exerted their skill; and thus the art of smelting being once lost, it is easy to conceive that many nations may have remained for ages without the use of metals, or with the use of such only as are found ready formed in the earth, or are easily fluxed from their ores.

The earth in a little time after the deluge, and long before it could have been peopled by the posterity of Noah, must have become covered with wood; the most obvious method of clearing a country of its wood, is setting it on fire: now in most mineral countries there are veins of metallic ores, which lie

con-

contiguous to the surface of the earth, and these having been fluxed whilst the woods growing over them were on fire, probably, suggested to many nations the first idea of smelting ores.

— Pow'rful gold first rais'd his head,  
And brass, and silver, and ignoble lead,  
When shady woods, on lofty mountains grown,  
Felt scorching fires; whether from thunder-  
thrown;

Or else by man's design the flames arose.

Whatever 'twas that gave these flames their  
birth,

Which burnt the towering trees and scorch'd  
the earth,

Hot streams of silver, gold, and lead, and brass,  
(copper)

As nature gave a hollow proper place,  
Descended down and form'd a glittering  
mass \*.

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There

\* Lucretius by Creech, Vol. II. p. 572.

There is no natural absurdity in this notion of the poet; and indeed it is confirmed by the testimony of various ancient historians, who speak of silver and other metals being melted out of the earth, during the burning of the woods upon the *Alps* and the *Pyrenees*. A similar circumstance is said to have happened in *Croatia* in the year 1761; a large mass of mixed metal, composed of copper, iron, tin and silver, having been fluxed, during the conflagration of a wood, which was accidentally set on fire\*.

The putting a quantity of ore upon a heap of wood, and setting the pile on fire, in conformity to the manner in which ores were melted during the burning of forests, was,  
it

\* Annual Register, 1761, p. 138.

it may be conjectured, the first rude process by which metals were extracted from their ores. But as the force of fire is greatly diminished, when the flame is suffered to expand itself, and as the air acts more forcibly in exciting fire, when it rushes upon it with greater velocity, it is likely, that the heap of wood and ore would soon be surrounded with a wall of stone, in which sufficient openings would be left for the entrance of the air, and thus a kind of furnace would be constructed. The *Peruvians*, we are told, “ had discovered the art of smelting and refining silver, either by the simple application of fire, or where the ore was more stubborn and impregnated with foreign substances, by placing it in small ovens or furnaces on high grounds,

grounds, so artificially constructed that the draught of air performed the function of a bellows, a machine with which they were totally unacquainted.\*

This method of smelting ores on high grounds, without the assistance of a bellows, at least of a bellows moved by water, seems to have been formerly practised in other countries as well as in *Peru*. When *M. Belon* travelled into *Greece*, he found the furnaces placed on the sides of rivulets, and observes, that all their bellows played with wheels turned by streams of water, yet formerly they had smelted their ores in a different manner: for upon the mountains

\* Robertson's Hist. of America.—Alonso Barba, Treatise of Metal, French Translation. Vol. I. p. 272.

tains of *Macedonia*, where mines had been wrought in the time of *Philip* the father of *Alexander*, great heaps of slag have been discovered, which are situated so far above any river of the country, that the furnaces from which they were formed, must, probably, have been wrought by the wind. There are several places in *Derbyshire* called *Boles* by the inhabitants, where lead has been anciently smelted, before the invention of moving bellows by water. These places are discovered by the slags of lead, which are found near them; there is no certain tradition concerning the manner in which the ore was smelted at these boles; it was, probably, as simple as that of the *Peruvians*; for in *Derbyshire*, as well as in *Peru*, they seem chiefly to have relied



relied upon the strength of the wind for the success of the operation; the boles being always situated upon high grounds, and mostly upon that side of a hill which faces the west. This situation was not fixed upon without design, since the wind blows in England, in the course of a year, near twice as many days from that quarter as from any other \*. A method is mentioned by *Erckern* † of smelting bismuth ore by the wind, and it seems as if the ore of lead might have been smelted at these  
boles,

\* As may appear from the following abridged state of the winds at London in the years 1774 and 1775.

|      | N                | S                | E                | W                | NW               | SE               | NE | SW                |      |
|------|------------------|------------------|------------------|------------------|------------------|------------------|----|-------------------|------|
| 1774 | 25               | 21               | 17 $\frac{1}{2}$ | 24               | 43 $\frac{1}{2}$ | 30               | 74 | 126 $\frac{1}{2}$ | days |
| 1775 | 22 $\frac{1}{2}$ | 21 $\frac{1}{2}$ | 11               | 18 $\frac{1}{2}$ | 39 $\frac{1}{2}$ | 32 $\frac{1}{2}$ | 72 | 148               |      |

Philos. Transf. 1774—5.

† See *Fleta Minor*, by Sir John Pettus,

boles, after the same manner. This method consists in putting the bismuth ore, when beat to a proper size, into small flat iron pans; these are set in a row contiguous to each other, in an open place, and when there is a strong wind, a fire of dry wood is made close to the pans, and on that side of them from which the wind blows; by this contrivance, the wind driving down the flame of the wood upon the pans, the ore contained in them is quickly melted. A pig of lead was dug up at one of the boles in the year 1766 on *Cromford* moor near *Matlock*; upon its under surface there is an inscription in *relievo*, from which it appears to have been smelted in the age of the Emperor *Adrian*; it is not very different in shape from the pigs which

are cast at present; it consists of several horizontal layers of unequal thicknesses, and there is an irregular hole in it running from the top to near the middle of its substance; from these appearances it seems as if it had been formed by pouring into a mould, at different times, several quantities of lead; and if lead had been smelted after the manner before mentioned of smelting bismuth ore, the several pans being emptied, at different times as they became ready, into the same mould, would have yielded a mass of lead divided into layers of unequal thicknesses, and resembling this Roman pig; for the hole in its surface was, probably, made accidentally, from the unequal cooling of the lead, or from some extraneous matter being lodged in it.

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The boles in Derbyshire are, probably, many of them of high antiquity, as appears from the pig of lead before mentioned; yet I have met with a passage in a writer of the last century, from which it is evident that the method of smelting lead on high grounds was then practised in the Peak. “ The lead-stones in the Peak lie but just within the ground next to the upper crust of the earth. They melt the lead upon the top of the hills that lie open to the west wind; making their fires to melt it as soon as the west wind begins to blow; which wind by long experience they find holds longest of all others. But, for what reason I know not, since I should think lead were the easiest of all metals to melt, they

they make their fires extraordinary great.\*

The smelting of ore by the variable and uncertain action of the wind, must have been a troublesome process. It has therefore been universally disused, and the more regular blast of a bellows has been introduced in its stead. The invention of the bellows is attributed by *Strabo* to *Anacharsis* the Scythian: † but it is more probable, that he was the inventor of some improvement of this machine, than of the machine itself; for *Homer*, who lived long before the age of *Anacharsis*, describes *Vulcan* as employing twenty pair of bellows at once, in the formation of *Achilles's* shield.

\* Childrey's Britan. Bacon. 1661.

† *Strab.* Geog. Lib. VII.

shield.\* It is difficult to say when the art of moving bellows, by means of a water wheel, was first discovered; it is pretty certain, that the ancients did not know it; and that it was very generally known, amongst the Germans at least, in the time of Agricola, one of the first of our metallurgic writers, for he speaks of it in several places without any hint of its being a recent invention.†

The heat of the fire in a furnace depending much upon the force of the blast of air impelled against the fuel; and that force, other circumstances remaining the same, being in proportion to the quantity and velocity of the air; the application of a power  
able

\* *Iliad*. Lib. XVIII. v. 470.

† *Agric. de Re Metal.* published in 1550.  
p. 165. 338.

able suddenly to compress the largest bellows when swelled with air, could not fail of being considered by metallurgists, as an invention, whenever it was made, of the last importance. The moderns accordingly have, in many instances, worked over again, with considerable profit, the heaps of iron and other kinds of slag, from which the metal had been but imperfectly extracted, before the moving of bellows by water was discovered.

It is not fifty years since the *blast* or *hearth* furnace, was the only one in use for smelting lead ore in *Derbyshire*. In this furnace ore and charcoal, or ore and what they call white coal, which is wood dried but not charred, being placed in alternate layers, upon a hearth properly

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constructed, the fire is raised by the blast of a bellows, moved by a water wheel; the ore is soon smelted by the violence of the fire, and the lead as it is produced trickles down a proper channel, into a place contrived for its reception. There are not at present, I believe, above one or two of these *ore hearths* in the whole county of Derby; this kind of furnace, however, is not likely to go entirely out of use, since it is frequently applied to the extracting lead from the *slag* which is produced, either at the *ore hearth*, or the *cupola* furnace, and it is then called a *slag hearth*; and the lead thus obtained is called *slag lead*: the fire in a slag hearth is made of the cinder of pitcoal, instead of charcoal.

The furnace called a *cupol* or *cu-*



*pola*, in which ores are smelted by the flame of pitcoal, is said to have been invented about the year 1698, by a physician named *Wright*\*, though *Beccher* may, perhaps, be thought to have a prior claim to its invention or introduction from Germany†. But whoever was the first inventor of the cupola, it is now in general use, not only in Derbyshire and other counties, for the smelting of the ores of lead, but both at home and abroad, where it is called the English furnace, for the smelting of copper ores. This furnace is so contrived, that the ore is melted, not by coming into immediate contact with the fuel, but by the reverberation of the flame upon it. The bottom of the furnace on which the  
lead

\* *Essais des Mines*, Vol. II. p. 114.

† See Vol. I. p. 33.

lead ore is placed, is somewhat concave, shelving from the sides towards the middle ; its roof is low and arched, resembling the roof of a baker's oven ; the fire is placed at one end of the furnace, upon an iron grate, to the bottom of which the air has free access ; at the other end opposite to the fire-place, is a high perpendicular chimney ; the direction of the flame, when all the apertures in the sides of the furnace are closed up, is necessarily determined by the stream of air which enters at the grate, towards the chimney, and intending thither it strikes upon the roof of the furnace, and being reverberated from thence upon the ore, it soon melts it.

It is not always an easy matter to meet with a current of water suffi-

cient to move the bellows required in smelting on an hearth furnace; and to carry the ore from the mine where it is dug to a considerable distance to be smelted, is attended with great expence; this expence is saved by smelting in the cupola furnace, which not requiring the use of bellows, may be constructed any where. Wood is very scarce in every mining county in England; and though pitcoal costs ten or twelve shillings a ton in Derbyshire, yet they can smelt a definite quantity of ore in the cupola, at a far less expence by means of pitcoal than of wood. — The flame which plays upon the surface of the ore and smelts it in a cupola furnace, is not driven against it with much violence; by this means  
 small

small particles of ore, called *belland*, may be smelted in a cupola furnace with great convenience, which would be driven away, if exposed to the fierce blast of a pair of bellows in a hearth furnace. — These are some of the advantages attending the use of a cupola in preference to a hearth furnace; and to these may be added one superior to all the rest, — the preservation of the workmen's lives; the noxious particles of lead are carried up the chimney in a cupola, whilst they are driven in the face of the hearth smelter at every blast of the bellows.

They generally put into the cupola furnace a ton of ore, previously beat small and properly dressed, at one time; this quantity they call a *charge*; if the ore is very poor in lead, they put in somewhat more, and they

work off three charges of ore in every twenty-four hours. In about six hours from the time of charging the ore becomes as fluid as milk. Before the ore becomes fluid, and even whilst it continues in a state of fusion, a considerable portion of its weight is carried off through the chimney; what remains in the furnace consists of two different substances,—of the lead, for the obtaining of which the process was commenced,—and of the *slag* or *scoria*. The proportion between these parts is not always the same, even in the same kind of ore; it depending much upon the management of the fire. The lead, being heavier than the slag, sinks through it as it is formed, and settles into the concavity of the bottom of the furnace. The pure slag, accord-

according to the idea here given, is that part of the ore of lead which is neither driven off by the heat of the furnace, nor changed into lead. In order to obtain the lead free from the slag which swims over it, the smelters usually throw in about a bushel of lime; not, as is usually supposed, in order to contribute towards the more perfect fusion of the ore, but to dry up the slag which floats upon the surface of the lead, and which, being as liquid as lead, might otherwise flow out along with it. The slag being thus thickened by an admixture of lime, is raked up towards the sides of the furnace, and the lead is left at the bottom. There is a hole in one of the sides of the furnace, which is properly stopped during the smelting

of the ore; when the slag is raked off, this hole is opened, and being situated lower than the lead in the furnace, the lead gushes through it into an iron pot placed contiguous to the side of the furnace; from this pot it is laded into iron moulds; each containing what they call a pig of lead; the pigs, when cold, being ordinarily stamped with the maker's name, are sold under the name of *ore lead*. After the lead has all flowed out of the furnace, they stop up the tap hole, and drawing down the slag and lime into the middle of the furnace, they raise the fire till the mixture of slag and lime, which they simply term slag, is rendered very liquid; upon this liquid mass, they throw another quantity of lime to dry it up as in the former  
part

part of the process. This second mixture of slag and lime is then raked out of the furnace, and the small portion of lead separated from the fusion of the first, generally to the amount of twenty or thirty pounds, being let out of the furnace, a new charge of ore is put in, and the operation re-commenced. In order to spare the lime, and the expence of fuel attending the fluxing of the mixture of lime and slag, they have in some furnaces lately contrived a hole, through which they suffer the main part of the liquid slag to flow out, before they tap the furnace for the lead; upon the little remaining slag they throw a small portion of lime, and draw the mixture out of the furnace without smelting it. This kind of  
fur-



furnace they have nick-named a *Maccaroni*.

The process of smelting here described, appears to be defective in some points, which I will take the liberty to mention, and at the same time suggest the means of improvement; without, however, presuming to say, how far it may be expedient to adopt the proposed alterations; being sensible that what may appear very feasible in theory, or may even answer in small assays, may not be practicable in large works.

The first alteration which I would propose to the consideration of the lead smelters, is to substitute an horizontal chimney of two or three hundred yards in length, in the place of the perpendicular one now in use. In the preceding Essay, which

which was first published in 1778, mention is made of the probability of saving a large quantity of sublimed lead, by making the smoke which rises from the ore pass through an horizontal chimney, with various windings to condense the vapour. I have since conversed with some of the principal lead smelters in *Derbyshire*, and find that I had over-rated the quantity of this sublimed lead; the weight of the *scoria* from a ton of ore, amounting to more than I had supposed; they were all of them, however, of opinion, that the plan I had proposed for saving the sublimate, was a very rational one. But so difficult is it to wean artists from their ancient ways of operating, that I question very much whether any of them would:

would ever have adopted the plan they approved, if an horizontal chimney, which was built a little time ago in *Middleton Dale*, for a quite different purpose, had not given them a full proof of the practicability of saving the sublimate of lead, which is lost in the ordinary method of smelting. This chimney was built on the side of an hill to prevent some adjoining pastures from being injured by the smoke of the furnace. It not only answers that end, but it is found also to collect considerable quantities of the lead, which is sublimed during the smelting of the ore; this sublimed lead is of a whitish cast, and is sold to the painters at ten or twelve pounds a ton; it might perhaps be converted into red lead with still more profit.

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A second circumstance to be attended to in the smelting of lead ore, is the saving the sulphur contained in it. The pure lead ore of Derbyshire contains between an eighth and a ninth part of its weight of sulphur; but as the ore which is smelted is never pure, being mixed with particles of *spar, cawk, limestone, brazil*, and other substances, which the miners call *deads*, we shall be high enough in our supposition, if we say that the ordinary ore contains a tenth of its weight of sulphur; it may not, probably, contain so much, but even a twelfth part, could it be collected at a small expence, would be an object of great importance to the smelter. In the common method of smelting lead ore there is no appearance of the sulphur it contains,

it

it is consumed by the flame of the furnace, as soon as it is separated from the ore; an attentive observer may, indeed, by looking into the furnace, distinguish a diversity in the colour of the flame, at different periods of the process; during the first three or four hours after the ore is put into the furnace, the flame has a bluish tint, proceeding no doubt from the sulphur which, in being sublimed from the ore, is inflamed: after all the sulphur is separated from the ore, the flame has a whitish cast, and then, and not before, the fire may be raised for finishing the operation; for if the fire be made strong before the sulphur be dispersed, the quantity of lead is less, probably, for two reasons; the sulphur unites itself in part to the lead which

is

is formed, and by this union becomes inseparable from it; for the sulphur cannot without much difficulty be separated from an artificial mixture of lead and sulphur, when the two ingredients have been fused together.—2. The sulphur, whilst it continues united to the lead in the natural ore, renders the ore volatile, so that in a strong heat a great portion of it is driven off. Hence, very sulphureous ores should be roasted for a long time with a gentle heat, and in this proper management of the fire, principally consists the superiority of one smelter above another.

An old lead smelter informed me that he had often reduced a ton of ore to 16 hundred weight by roasting it, but that he did not obtain more

more metal from it by a subsequent fusion, than if he had fluxed it without a previous roasting. This may be true of some sorts of ore, but it is not true of very sulphureous ores. Indeed the fire may be so regulated in a cupola furnace, as to make it answer the purpose of a roasting and a smelting furnace at the same time. I have seen much lead lost by smelting a ton of sulphureous ore in eight hours, which might have been saved, if the fire had at first been kept so gentle as to have allowed twelve hours for finishing the operation.

Sulphur cannot be separated from lead ore in close vessels, and the lead ore melts with so small a degree of heat, that there may be more difficulty in procuring the sulphur from the ~~ores~~ of lead, than from those of copper

copper or iron, however, I am far from thinking the matter impracticable, though I have not yet hit upon the method of doing it; and the following reflections may, perhaps, tend to supersede the necessity of collecting the sulphur in substance.

When it is said that the sulphur is consumed by the flame of the furnace as soon as it is separated from the ore, the reader will please to recollect, that sulphur consists of two parts,—of an inflammable part, by which it is rendered combustible,—and of an acid part, which is set at liberty, in the form of vapour, during the burning of the sulphur. Now this acid, though it may be driven out of the furnace in the form of a vapour, yet it is incapable of being thereby decomposed; it still



continues to be an acid ; and, could the vapour be condensed, might answer all the same purposes as the acid of vitriol ; since all the acid of vitriol, now used in commerce, is actually procured from the burning of sulphur. That the fact, with respect to the acid not being decomposed, is as I have stated it, may be readily proved. The smoke which issues out of the chimney for some hours after each fresh charge of ore, has a suffocating smell, perfectly resembling the smell of burning brimstone ; and if a wet cloth, or a wet hand, be held in it for a very short space of time, and afterwards applied to the tongue, a strong acid will be sensibly perceived. Various methods may be invented for condensing this acid vapour, and, probably,

more commodious than the following one, which, however, I will just take the liberty of mentioning, as, if it should not succeed, the trial will be attended with very little expence.

Supposing then an horizontal chimney to be built, let the end farthest from the fire be turned up by a tube of earthen ware, or otherwise, so that the sulphureous acid may issue out in a direction parallel to the flue of the chimney, and at the distance of about a foot and an half above it. Let a number of large globular vessels be made of either glass or lead; each of these globes must have two necks, so as to be capable of being inserted into one another; let these vessels be placed on the flue of the chimney, the neck of the first being inserted into

the tube through which we have supposed the sulphureous acid to issue, and the neck of the last being left open, for fear of injuring the draught of the furnace. Let each of these globular vessels contain a small quantity of water, then it is conceived, that the heat of the flue will raise the water into vapour, and that this watery vapour will be the means of condensing the sulphureous acid vapour, if not wholly, at least in such a degree as may render the undertaking profitable. When the sulphur is all consumed, the draught of the furnace may be suffered to have its ordinary exit at the end of the horizontal chimney, by a very slight contrivance of a moveable damper. Since the first publication of the preceding Essay, I have seen  
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an horizontal chimney at the copper works near Liverpool, where every thing I had said concerning the probability of saving sulphur by roasting lead ore, is verified with respect to copper ore; and I believe a patent has been granted to some individual for this mode of collecting sulphur. Sulphur might be obtained with equal facility from the *pyrites* which is found amongst coal, and this application of the *pyrites* might, probably, be more lucrative than the present one—making green vitriol\*.

A third circumstance, which requires the utmost care of the lead smelter, is the leaving as little lead as possible in the slag. Near every smelting house there are thousands of tons of slag, which, when properly  
 T 3                      assayed,

\* Vol. I. p. 229.

assayed, are found to yield from one eighth to one tenth of their weight of lead, though no person has yet discovered a method of extracting so much from them when smelted in large quantities; and indeed the smelters are so little able to obtain all the lead contained in them, that in many places they never attempt to extract any part of it: in some places where they do attempt it, I have known the proprietor of the slag allow the smelters 20s. for every pig of lead they procured of the value of 38s. besides furnishing them with fuel: and yet the men employed in such an unwholesome business, seldom made above 7s. a week of their labour. This fusion of the slag of a cupola furnace is made, as has been mentioned, at a hearth furnace ;

nace; the coal cinder, which they use as fuel, and the slag, are soon melted by the strong blast of the bellows into a black mass, which, when the fire is very strong, becomes a perfect glass; this black mass, even in its most liquid state, is very tenacious, and hinders many of the particles of lead from subsiding; and it being from time to time removed from the furnace, a considerable quantity of lead is left in it, and thereby lost. A principal part of the lead contained in the slag of the cupola furnace, is not, I apprehend, in the form of a metal, but in the form of a litharge or calcined lead: a portion of the lead, in being smelted from its ore, is calcined by the violence of the fire; this calcined lead is not only very vitrifiable of itself, but it

helps to vitrify the spar which is mixed with the ore, and thus constitutes the liquid scoria; might it not be useful to throw a quantity of charcoal dust upon the liquid scoria in the cupola furnace, in order that the calcined lead might be converted into lead by uniting itself to the inflammable principle of the charcoal? — Iron will not unite with lead, but it readily unites with sulphur, and, when added to a mixture of lead and sulphur, it will absorb the sulphur, leaving the lead in its metallic form; might it not be useful to flux sulphureous lead ores in conjunction with the scales or other refuse pieces of iron, or even with some sorts of iron ore? — The smelter's great care should be to extract as much lead as possible at the first

first operation of smelting the ore, and to leave the slag as poor as possible ; but if he should still find either the slag of the cupola furnace, or that of the hearth furnace, containing much lead (as that even of the hearth furnace certainly does), he may, perhaps, find it worth his while to reduce the slag into a powder by a stamping mill, or by laying it in highways to be ground by the carts, or by some other contrivance, and then he may separate the stony part of the slag from the metallic, by washing the whole in water, inasmuch as the metallic part is far heavier than the other.

I estimated the weights of several pieces of slag, and found them to differ very much from each other ; this difference is principally to be  
at-



attributed to the different quantities of lead left in them.

Weight of a cubic foot of

|  | Avoir. oz.       |
|--|------------------|
| Slag from a cupola furnace, where }<br>no lime was used - - - - - }        | 374 <sup>2</sup> |
| Black slag from a hearth furnace - -                                       | 365 <sup>2</sup> |
| Another piece - - - - -  | 361 <sup>2</sup> |
| Black slag from another hearth fur- }<br>nace---struck fire with steel - } | 337 <sup>8</sup> |
| Black glass-slag - - - - -   | 337 <sup>1</sup> |

This may not be an improper place to add a word or two concerning the *Derbyshire Toadstone*, which constitutes one of the principal strata in the mining country\*, and which is supposed to have been in its origin a *slag* thrown out by a *volcano*. It perfectly resembles some of the specimens, I have seen, of one of the sorts of the *lava* of *Kesuvius*, not only in

\* See Vol. II. p. 206.

in the hardness of its texture, and blackness of its colour, but in its weight; a cubic foot of some sorts of Derbyshire toadstone weighing more, and of other less than a cubic foot of the Vesuvian lava, which it resembles. The streets of *London* have some of them been paved, of late years, with a *toadstone* from *Scotland*, of the same nature as the Derbyshire toadstone; and the streets of *Naples* have for many centuries past been paved with the lava from Vesuvius which resembles toadstone. Neither the Derbyshire toadstone, nor that sort of Vesuvian lava which resembles it, seem to have experienced in their formation any great degree of heat; they are but in a half vitrified state: the toadstone I have frequently melted in a smith's forge into

into a black glass, and the Vesuvian lava gives a glass of the same kind. The air has a manifest action upon the Derbyshire toadstone, for it not only wastes away the spar which is found in the blebs of some sorts of toadstone, but it reduces into a brownish mould, fit for vegetation, the most hard and compact sorts; the Vesuvian lava is subject to the same change from the operation of the same cause.

Weight of a cubic foot of

|                                      | Avoir. oz. |
|--------------------------------------|------------|
| Toadstone hard and free from blebs - | 2884       |
| Vesuvian lava resembling toadstone - | 2865       |
| Iron slag, a greenish glass - - - -  | 2843       |
| Iron slag, a brownish glass - - - -  | 2729       |
| Iceland crystal---Mr. Cotes - - - -  | 2720       |
| Toadstone, decaying - - - - -        | 2680       |
| Another piece - - - - -              | 2662       |
| Another piece - - - - -              | 2558       |

ESSAY

## E S S. A Y IX.

### OF SILVER EXTRACTED FROM LEAD.

**W**E have no silver mines, properly speaking, in *Great Britain*, but we have plenty of lead, from which silver is, in some places, extracted with much profit. If the method of doing this had been known to the ancient *Britons*, it might have freed our country from the reproach of *Cicero*, who tells his friend *Atticus*, that there was not a scruple of silver in

in the whole island\* ; and in another place, he says, that he had heard there was neither gold nor silver in *Britain*†. The *Romans* had a very imperfect knowledge of this country in the time of *Cicero*, so that his account of the matter may not, perhaps, deserve to be much relied on ; we are certain, at least, that about fifty or sixty years afterwards, both gold and silver were reckoned by *Strabo* amongst the products of *Britain*‡ : hence, if the Britons did not understand the art of extracting silver from lead at the first invasion of the

\* — etiam illud jam cognitum est, neque argenti scrupulum esse ullum in illa insula (Britann.) Epist. ad Att. L. IV. E. XVII.

† Epist. Fam. L. VII. E. VII.

‡ L. IV. p. 305.—See also Tacitus's Life of Agricola.

the Romans, they soon learned it from their conquerors; and this becomes more probable, if it be admitted, that silver was coined in Britain in the time of *Augustus*\*.

Silver is so commonly contained in lead, that it is esteemed a very great curiosity to meet with lead which is intirely free from it: it has even been asserted, that there is no lead in the world, except that of *Villach* in *Carinthia*, which does not contain silver†.

The more ancient alchemists, not knowing, probably, that silver was so generally contained in lead, and yet

\* Sir John Pettus' *Fod. Reg.*

† Il n'y a point de plomb au monde, hormis celui de Villach, qui ne contient de l'argent. Lehman sur les Mines, Vol. I. p. 174.—See also *Philos. Transf.* for 1665, p. 10.

yet observing that lead, when treated according to their processes, often gave a portion of silver, were of opinion, that they could convert lead into silver\*. This was an easy mistake, and if they had obtained a portion of gold, they would, no doubt, have concluded, that they had transmuted the lead into gold; since there is no metal, perhaps, which does not *contain* a small quantity of gold, or from which gold may not be *separated* by long calcination. \*

*Lifter* had long ago observed, that all the English lead contained silver; and he speaks as having, by his own experiments, proved the existence of silver in the lead of at least thirty different mines †; nor has any per-  
son

\* Gebri Chem. L. I. C. XIX.

† *Lifter de Fontibus*, Cap. II. S. 9, 10.

son since his time, found lead wholly free from silver. The *Derbyshire* lead has been said to contain two grains of silver in a pound of lead\*. Every general observation of this kind is liable to much contravention from particular facts; because the quantity of silver contained in lead, is not only different according as the lead is fluxed from the ore of different mines, but it is very possible in an assay of the ore of the same mine to meet with one piece of ore which shall afford a lead yielding eight or ten times as much silver as another piece would do. This diversity arises from the ore itself being variable in quality in different parts of the same mine; and even different lumps of ore, though contiguous to each other, will

\* Oper. Min. Explicata, p. 263.



will often yield very different quantities of silver, from the same quantity of lead. This observation may explain the reason of the very opposite testimonies, which have been sometimes given in courts of justice, concerning the richness of a mine from particular assays; the plaintiffs and defendants, where the issue to be tried was the quantity of silver, having been severally interested in getting the best and the worst pieces of ore assayed, in order to support their respective claims. There was a notable instance of this with respect to the lead mine of *Est-kyr-kyr* in *Cardiganshire*, which was discovered in 1690. The law at that time adjudged every mine to be a *royal mine* the metal of which contained enough of gold or silver to compensate the charges

charges of refining, and the loss of the baser metal in which they were contained. In consequence of this law, the patentees of royal mines laid claim to the mine of *Est-kyr-kyr*, which was rich in silver, and they produced proof in *Westminster-hall*, that the lead of that mine contained to the value of sixty pounds of silver in every ton; whilst the proprietor produced proof, that it only contained to the value of four pounds of silver in a ton\*.

I have been informed by an intelligent person, that there are some lead ores in Great Britain, which, though very poor in lead, contain between three and four hundred ounces of silver in a ton of the lead. It is not to be expected that the pro-  
prietors

\* Some Account of Mines, p. 27.

prietors of these, or of any other mines rich in silver, should be forward in declaring to the world the quantity of silver which they contain. The proprietor indeed of a lead mine containing silver, may work the same, without any apprehension of its being taken from him, under the pretence of its being a *royal mine*; yet the crown, and persons claiming under it, have the right of pre-emption, of all the ore which may be raised. There was an act of parliament passed in the sixth year of *William and Mary*, intituled,—An act to prevent disputes and controversies concerning royal mines. — This act gave great quiet to the subject, by declaring, that every proprietor of a mine of copper, tin, iron, or lead, should continue in possession of

of the said mine, notwithstanding its being claimed as a royal mine, from its containing gold or silver: but it further enacted, that their majesties, their heirs and successors, and all claiming under them, should have the privilege of purchasing all the ore which should be raised out of such a mine, at the following prices; that is to say, paying for all ore washed, made clean, and merchantable, wherein is copper, after the rate of sixteen pounds a ton; for tin ore (except that raised in Devonshire and Cornwall) forty shillings; for iron ore forty shillings; and for lead ore nine pounds a ton. This standard price of nine pounds a ton for lead ore was, at the time it was fixed, much higher than the ordinary price of ore, in which there was no

silver worth extracting; the best kind of Derbyshire lead ore being, at present, generally worth no more than seven pounds a ton. It may deserve, however, the consideration of the legislature, whether the clause in the forementioned act, respecting the right of pre-emption, should not be wholly repealed; as there may be many lead mines in England very rich in silver, but which, on account of the difficulty of working them, cannot be entered upon with advantage, whilst this right subsists. As many lead mines, moreover, there are large quantities of steel-grained ore raised together with the ordinary sort; now it generally happens that the steel-grained ore is much richer in silver than the ordinary diced ore of Derbyshire; and it might, if separated

rated from the rest, be worked for silver; but whether from an apprehension of the operation of the clause we are speaking of, or from mere ignorance or inattention, all the sorts of ore, are mixed and smelted together.

Silver has formerly been extracted from lead in a great many places in this island. In the reign of Edward I, near 1600 pounds weight was obtained, in the course of three years, from a mine in *Devonshire*, which had been discovered towards the beginning of his reign; this mine is called a silver mine by the old writers, but it appears to have been a mine of lead which contained silver \*. The lead

\* Hollingshed's Chron. Vol. II. p. 316.  
See also, in the same author, a further account of

lead mines in *Cardiganshire* have at different periods afforded great quantities of silver: Sir *Hugh Middleton* is said to have cleared from them two thousand pounds a month\*, and to have been enabled thereby to undertake the great work of bringing the new river from *Ware* to *London*; and in allusion, probably, to these two great circumstances of his life, there are painted upon some of his pictures the two terms—*fontes*—*fadinae*. These same mines yielded, in the time of the great rebellion, eighty ounces of silver out of every ton of lead, and part of the king's army was paid with this silver, which

was

of silver extracted from the lead in *Devonshire* and *Cornwall* in the time of *Edward III.*

P. 413.

\* *Oper. Min. Explic.* p. 245.

was minted at *Shrewsbury*\*. A mint for the coinage of Welch silver had before that time been established in 1637 at *Aberystwith*; the indenture was granted to *Thomas Busbel* for the coining of half-crowns, shillings, six-pences, two-pences, and pennies, and the monies were to be stamped with the ostrich feathers on both sides†. In the year 1604 near three thousand ounces of this Welch bullion were minted, at one time, at the Tower‡. *Webster*, in his *History of Metals*, published in 1671, makes mention, from his own knowledge, of two places in *Craven*, in the west-riding of *Yorkshire*, where formerly good silver ore (lead ore abounding in

\* Sir J. Pettus, *Essay on Metal. Works.*

† Rym. Fœd. Tom. XX. 164.

‡ *Some Account of Mines*, p. 6.



in silver) had been gotten. One of the places was *Brungbill* moor in the parish of *Slaidburn*, the ore of which held about the value of sixty-seven pounds of silver in a ton: the other was *Skelkorn* field within the township of *Rimmington* in the parish of *Gif-burn*; it had formerly belonged to one *Pudsey*, who is supposed to have coined the silver he got out of his mine, there being many shillings in that county which the common people called *Pudsey's shillings*\*.

There is not at present any place in *Derbyshire* where silver is extracted from lead. A work of this kind was established a few years ago not far from *Matlock*, and the lead yielded fourteen ounces of silver from a ton; but the mine which afforded the

\* Webster's Metal. p. 21.

the ore was soon exhausted, or became too difficult to be worked with profit. There is a lead mine in *Patterdale* near *Keswick*, which yields between fifty and sixty ounces of silver from a ton of the lead: the ore of this mine is reckoned to be poor in lead; and indeed it is very commonly observed, that the poorest lead ores yield the most silver, so that much silver is probably thrown away, for want of having the ores of the poorest sort properly assayed.

The quantity of lead smelted annually in Derbyshire, may be estimated at 7,500 tons upon an average; fifty years ago the average was, probably, 10,000 tons a year, but we put it high enough in supposing it, at present, to amount to 7,500 tons: I have never been able to get any  
proper

proper information, concerning the quantity of lead annually smelted in other parts of Great Britain, but for the illustration of the subject we are upon, let us suppose, that in the whole kingdom 30,000 tons of lead are annually smelted, and that at a medium each ton of lead would yield 12 ounces of silver; then would there be, if all the lead was refined, a saving of three ounces of silver from each ton of lead, or ninety thousand ounces in the whole; our English workmen reckoning that nine ounces of silver are full adequate to the expence of refining a ton of lead, added to that of the lead which is lost during the operation.

The general manner of extracting silver from lead is every where the same; it is very simple, depending  
upon

upon the different essential properties of the two metals. — It is an essential property of lead, when melted in the open air, to lose its metallic appearance, and to burn away into a kind of earth. — It is an essential property of silver not to burn away, or to lose its metallic appearance when exposed to the action of the strongest fires, in the open air. Hence, when a mass of metal, consisting of lead and silver, is melted in the open air, the lead will be burned to ashes, and the silver remaining unaltered, it is easy to understand how the silver may be extracted from the lead; for being heavier than the ashes of the lead, and incapable of mixing with them (since no metal is miscible with an earth), it will sink to the bottom of the

the

the vessel in which the mass is melted. Iron, tin, and copper, resemble lead, in being convertible into a kind of ashes, when exposed to the action of air and fire, and gold resembles silver in not undergoing any change from such action; hence either gold or silver, or a mass consisting of both, may be purified from any or all of these metals by the mere operation of fusion; for these metals will rise to the top of the vessel, in which the fusion is made, in the form of an earth or dross, leaving the gold or silver pure at the bottom.

The ancients certainly knew that silver could be purified from the base metals by the force of fire.—  
*The house of Israel is to me become dross: all they are brass (copper), and tin,*

*tin, and iron, and lead, in the midst of the furnace, they are even the dross of silver* \*. And as we read of silver being purified seven times in a furnace of earth †, it may, perhaps, be inferred, that the method of refining silver, which was then in use, consisted in reducing the base metals into earth, by a repetition of the process of fusion. This inference, it must be owned, is rendered doubtful by a passage in *Jeremiah*;—*the bellows are burned, the lead is consumed of the fire, the founder melteth in vain* ‡. —This passage is somewhat ambiguous, and interpreters translate the original Hebrew differently, but most of them collect from it, that the  
founder

\* Ezek. xxii. 18.

† Ps. xii. 6.

‡ Jerem. vi. 29.

founder added lead to the mixed mass which he wanted to refine.

Lead, when reduced to an earth by being burned in the open air, may, in a stronger degree of heat, be converted into a yellowish glass \*, which

\* Other metallic substances yield coloured glasses, either when vitrified alone, or in conjunction with pure glass. In enamel and china painting, they prepare rose red and purple colours from gold; scarlet reds from iron, or vitriols that partake of it; greens from copper; blues from cobalt; blacks from magnesia, zaffer, and scales of iron; yellows from silver antimony, Naples yellow, and crocus martis; white from tin. The same substance yields different colours, according to the degree of heat to which it is exposed; thus, the green colour of common glass bottles, which proceeds from the iron contained in the sand and vegetable ashes from which the glass is made, is changed into a blue by a stronger degree of heat.

which has the property of greatly contributing to the easy vitrification of all earthy substances ; hence, when gold or silver are mixed with iron, copper, or tin, it is usual to add to the mixed mass a quantity of lead, in order to accelerate the purification ; for the lead will be converted into glass, and this glass will vitrify all the extraneous substances with which the gold or silver are polluted, without exerting the least action upon the precious metals themselves.

I do not know upon what grounds one of the most distinguished chemists of the age has asserted, “ that the refining of gold and silver merely by the action of the fire was the only method anciently known.” † and

† Chem. Dict. by M. M. ———  
Refining.



and that the doing it by the addition of lead, is a discovery with which the ancients were unacquainted. Not to insist upon what has been quoted from *Jeremiab*; in *Diodorus Siculus* there is a very minute description of the manner of working some gold mines in the confines of *Egypt* and *Arabia*; this description was probably written on the spot when he visited that country, but the mode of operation seems to have been derived from a more early period; as the discovery of the mines is attributed by him to some of the most ancient *Ægyptian* kings; amongst other particularities, he takes notice of their melting the mineral in conjunction with a little tin, some small portion of salt, and a lump of *lead*.\*

*Strabo*

\* Diod. Sic. Lib. III. p. 183—189.

*Strabo* quotes *Polybius* as speaking of a silver ore, which, after being five times washed, was melted with lead, and became pure silver. Unfortunately this part of the works of *Polybius* is lost, or we might have had a more circumstantial knowledge of the processes by which the ancients extracted silver from its ores, as *Strabo* says, that he omitted *Polybius's* account of this matter, because of its prolixity.\* *Pliny* probably has an allusion to the use of lead in refining silver, when he says, that a silver ore in the form of an earth could not be melted except in conjunction with lead or the ore of lead.† A more diligent search into the writings of the ancients would, doubtless,

\* *Strab. Geo. Lib. II. p. 221.*

† *Plin. Hist. Nat. Lib. XXXIII. C. 6.*

less, furnish more authorities upon the point, but these may be sufficient to induce us to believe, that they were not unacquainted with the use of lead in refining gold and silver.—But to return to the manner of extracting silver from lead.

The vessel in which the workmen melt the mass of silver and lead, is of a shallow form, that a large surface of the melted mass may be exposed to the air; it is made usually of four measures of the ashes of calcined bones, and of one measure of unwashed fern ashes, and is called a *test*.\* This vessel is very porous, but

\* Tests are sometimes made of clay and other materials, and metallurgic writers often order the wood ashes to be washed, lest the alkaline salts which they contain should tend to vitrify the test; but a very good refiner

But not so much as to imbibe the metal, whilst it continues in the form of a metal; but as the earth, into which the lead is soon reduced by the action of the fire, becomes melted, the test imbibes a portion of it in that liquid state, the other portion is driven off (as cream is blown off from milk) from the surface of the melted mass, by the blast of a bellows. The liquid, half vitrified, earth of lead, which is thus driven off, concretes into hard masses of a scaly texture, and is called in that state *litharge*, or silver stone, from the manner of its being produced, or from an idle notion of its containing

finer at Holywell informed me, that he always used the ashes without washing them, as the vessel became thereby less apt to crumble into pieces.

taining much silver. The litharge which is first formed is whitish, that which experiences a greater degree of heat is red ; the colour of the litharge is also influenced by that of the other metals, which may chance to be mixed with the mass of lead and silver. When the surface of the melted mass becomes white, and throws up no more litharge, the operation is finished ; but as the remaining silver is not quite pure, since it contains a small portion of lead, from which the degree of heat requisite for melting the mixed mass cannot readily free it, it is taken to a refining furnace, and rendered quite pure, at least from lead, by *cupellation*. This process consists in melting the silver obtained from the first operation, in a vessel made of the same

same materials as the test, and which from its resemblance to a wide-mouthed cup, has been called a *cupel*. The cupel being exposed to a stronger heat than the test, the lead which had escaped the action of the fire on the test; is now driven out from the silver, and being converted into litharge, is absorbed by the cupel; and by this means the silver is purified from every metal except gold; for it is not necessary, on this occasion, to remark, that a minute portion of copper, when there happens to be any in a mass of silver and lead, probably escapes the action of the fire in cupelling gold or silver.

There are several smelting houses at *Holywell* in *Flintshire*, where silver is extracted from lead; Mr. Pennant\*

x 4

has

\* Tour through Wales.

has given the following account of the quantity of silver extracted at one of the largest of these houses in the course of six years.

|             | ounces. |             | ounces. |
|-------------|---------|-------------|---------|
| Year 1754 - | 12160   | Year 1774 - | 5693    |
| 1755 -      | 1276    | 1775 -      | 6704    |
| 1756 -      | 7341    | 1776 -      | 4347    |

The silver obtained from lead at *Holywell*, is chiefly sold to the manufacturers at *Birmingham* and *Sheffield*. Much silver is also extracted from lead in *Northumberland*.

At *Holywell* they usually work off three tons of lead at one operation, the quantity of silver which they procure, is variable according to the richness of the lead; a few years ago they were refining lead from an ore found in the *Isle of Man*, and it gave them about 60 ounces at every  
ope-

operation, or 20 ounces in a ton of the lead. The litharge ordinarily obtained from three tons of lead amounts to 58 hundred weight; this litharge may either be changed into red lead by calcination, or it may be reduced into lead again by being fluxed with charcoal, or any other matter containing the inflammable principle,\* but when it is *reduced* they seldom obtain more than 52 hundred weight of lead,† so that by

ex-

\* Lead from litharge is, generally speaking, worth five shillings a ton more than ore lead, as the plumbers esteem it softer and fitter for making sheet lead; yet the litharge lead from the ore of the Isle of Man here mentioned, was found quite unfit for making sheet lead, on account, probably, of the ore having held other metals beside silver and lead.

† In the foreign works they estimate the loss of weight, which the litharge sustains in being

being



extracting the silver, there is a loss of eight hundred weight in three tons of lead. It has been said that the *Dutch* can extract the silver from three tons of lead, and not lose above six hundred weight \* upon converting the litharge into lead, and that this superior skill, aided, probably, by their superior industry, enabled them to purchase our lead, and to extract the silver from such as could not be refined here with advantage: I have been informed, however, by an experienced refiner in Derbyshire, that he could extract the silver without losing quite so much as six hundred

being reduced into lead, at a sixth part of the weight of the litharge, or  $9\frac{2}{3}$  hundred weight from 58 hundred weight of litharge. *Essais des Mines*, Tom. II. p. 401.

\* *Wehler's Metal*, p. 233.

dred weight in three tons of lead; I make no question that the loss depends, in some measure, on the quality of the lead. It has been remarked before, that lead, which does not contain nine ounces of silver in a ton, is not thought worth the refining; the smallest quantity which can be extracted with profit, must depend much upon the price of lead, all expences attending the several processes being the same. For eight hundred weight of lead, which may be assumed at a medium as the loss sustained during the operations of *refining* and *reducing*, is worth 6l. when lead is at 15l. a ton, and it is worth only 4l. 16s. when it is at 12l. a ton. The value of 27 ounces of silver, which we suppose to be the quantity separable from three tons of

of

of lead, is 7l. 10s. 9d. at 5s. 7d. an ounce; hence, the difference between the value of the silver obtained and that of the lead lost, would, when lead is at 15l. a ton, be 1l. 10s. 9d. and when lead is as low as 12l. a ton, it would amount to 2l. 14s. 9d. In the times of Sir *John Pettus*, the usual allowance for waste in refining and reducing of lead, was three hundred weight in a ton, or nine hundred weight in three tons, and the lead was valued at 12l. a ton,\* so that lead has altered very little in its price in the course of above one hundred years.

Silver is here valued at 5s. 7d. an ounce; this requires some explanation. A pound of *standard* silver in England, consists of 11  
ounces

\* *Fodine Reg.* p. 10.

ounces and 2 pennyweights of *fine* silver, and of 18 pennyweights of copper; in other words, every mass of *standard* silver consisting of 40 parts by weight, is composed of 27 parts of *fine* silver, and of 3 parts of copper; the copper is called the *alloy*. All nations use some alloy both in their gold and silver; partly with a view of rendering these metals harder, and partly because it would require much labour and expence to free them wholly from that small portion of copper, which in their ordinary state, as fluxed from their ores, they are generally found to contain. A pound of *standard* silver is coined into 62 shillings, hence the *Mint* price of an ounce of *standard* silver would be a twelfth part of 62 shillings, or 5s. 2d. From hence

it might be shewn, by the rule of proportion, that the *market* price of an ounce of *fine* silver, which contains no copper, will be 5s. 7d. at the least. The market price of silver bullion does not wholly depend on the mint price, it can never be lower than that, but, from the operation of various causes, it may exceed it. †—*Standard* gold with us consists of 11 parts of *fine* gold, and of 1 part of copper, or of a mixture of silver and copper; and a pound or 12 ounces of standard gold, is coined into  $44\frac{1}{2}$  guineas; hence the price of an ounce of standard gold is 3l. 17s.  $10\frac{1}{2}$ d. and the price of an ounce of *fine* gold is 4l. 4s.  $11\frac{1}{2}$ d. Foreign gold trinkets stain the hands more, and have a more coppery

† Essay on Money and Coins, p. 2. and 55.

pery look than English ones ; and in fact they are made of gold which is alloyed with a much greater proportion of copper, than the standard gold of England ; yet, when an enamel is to be fixed on gold, one of the most experienced of the foreign enamellers† recommends the use of gold, which has the same alloy as the English standard gold, or two parts alloy, and twenty-two parts of fine gold.

Copper communicates a smell both to gold and silver. The *Roman specula*, which they used as looking glasses, in *Pliny's* time were commonly made of silver, but the silver was alloyed with much copper ; for we find a cunning waiting maid in *Plautus* advising her mistress

† M. de Montamy, *Traité des Couleurs*.

tréfs to wipe her fingers after having handled a speculum, lest her paramour, from the smell of her fingers, should suspect her of having received silver from some other lover.

Ut speculum tenuisti, metuo ne oleant argentum manus,  
 Ne usque argentum te accepisse suspicetur  
 Philolacles.\*

\* Plaut. Most. Act. I.

## E S S A Y X.

### OF RED AND WHITE LEAD.

**I**F the reader does not know what *minium* or *red lead* is, I would wish him to send for a few ounces of it to his painter or apothecary.— Supposing him to have a parcel of red lead before his eyes, the first thing which will strike him is its vivid colour verging a little towards orange; if he crumbles it between



his fingers, he will find it to be an almost impalpable powder; if he poizes it in his hand, he will perceive it to be much heavier than either brick dust or red ochre, with which substances it is sometimes adulterated; if he compares it with a piece of lead, he will be astonished how it can be either produced from lead, or be capable of being, by a very slight operation, *reduced* into lead again.

It has been mentioned in the preceding Essay, that red lead is made from *litharge* at *Holywell*: this red lead, which is made from litharge, is not perhaps, in all its properties, of quite the same kind with that which is made directly from lead; at least I have been informed, that the makers of flint glass, who use much red  
 lead.

lead in the composition of that glass, are of opinion, that the litharge red lead does not flux so well as that which is made from the direct calcination of lead, as is practised in *Derbyshire*. There are in that country nine red-lead mills or furnaces, all of which are much upon the same construction.

The furnace is very like a baker's oven, its vaulted roof is not at a great distance from the bottom or floor, on each side of the furnace there are two party walls, rising from the floor of the furnace, but not reaching to the roof; into the intervals, between these walls and the sides of the furnace, the pit-coal is put, the flame of which being drawn over the party walls, and striking upon the roof, is from thence reflected

down upon the lead, which is placed in a cavity at the bottom, by which means the lead is soon melted. The surface of melted lead, when exposed to the open air, instantly becomes covered with a dusky pellicle; and this pellicle being removed, another is formed, and thus by removing the pellicle, as fast as it forms, the greatest part of the lead is changed into a yellowish green powder. This yellowish powder is then ground very fine in a mill, and being washed, in order to separate it from such parts of the lead as are still in their metallic state, it becomes of an uniform yellow colour, and, when it is dried to a proper consistency, it is thrown back again into the furnace, and being constantly stirred, so that all its parts may be exposed to the  
 action

action of the flame of the pit coal,\* in about 48 hours it becomes *red lead*, and is taken out for use.

The colour of the red lead admits some variety, which is occasioned by the different degrees of heat. If the heat is too small, instead of red it is yellow or orange coloured; if it is too great, the red colour is changed into a dirty white; between these two extremes it is subject to some diversity of shades of red, which cannot well be noticed or described, except by those who are engaged in the making of it.

It has been asserted, that the reverberation of the flame and smoke upon the surface of the lead, is not a necessary circumstance in giving it a red colour\*; but that it will acquire

\* Infit. de Chym. par M. Demachy, p. 528.

quire this colour by a long calcination without coming into contact with the flame. The truth of this assertion I think may be doubted. I have more than once calcined lead for above 60 hours, without suffering the flame of the fire to touch it during any part of the process, but by this method I could never obtain any thing better than a dirty red, resembling the red of brick dust, which is very different from the colour of red lead; and even this dirty red was changed into a yellow colour, by augmenting the degree of heat with which the lead had been calcined. The method of making red lead is very well understood in *England* and *Holland*, but not in *France*; and the French workmen are  
of

of opinion that it cannot be made by the flame of wood fires\*.

During the making of red lead, part of it is volatilized, there rises up from it a vapour, which attaches itself to the roof of the furnace, and forms solid lumps. These lumps are of a yellowish white colour mixed with pale green and some reddish streaks, wherein are frequently small red crystals, resembling such as may be artificially formed by subliming sulphur and arsenic together. The workmen call the whole of what is separated from the lead in the form of smoke, sulphur: when this sublimed matter is detached from the roof of the furnace, the red parts

\* Mem. de l'Acad. des Scien. 1770.—  
Elemens de Mineral. par M. Sage, Vol. II.  
p. 248.

are converted by a subsequent process, into red lead; and the yellow ones are sent to the smelting furnaces, to be run down again into lead. The quantity of this sublimate amounts to about five hundred weight in making one hundred tons of red lead. The proportion here assigned is not wholly to be relied on, since the smoke arising from the lead forms itself into larger masses, and in less time, when it is not constantly swept from the roof of the furnace than when it is; and the workmen endeavour to keep the roof as free from it as they can, because a small portion of it injures the colour of a large quantity of the red lead with which it happens to be mixed.

A ton or twenty hundred weight  
of

of lead generally gives twenty-two hundred weight of red lead, notwithstanding the loss of substance which the lead evidently sustains from the copious smoke which arises from it during the operation. Some authors tell us, that the increase in the weight of the red lead is double what I have here mentioned: thus, *Orschall* speaking of the red lead made at *Nuremberg*, assures us, that 100 pounds of lead yield 120 pounds, and sometimes even more, of red lead\*. It is not impossible that, according to the different manners of conducting the process, there may be a difference in the quantity of weight which the red lead acquires: I had my information from some of the most  
expe-

\* *Orsch. Metal. French Transl.* p. 100. —  
*M. Sage's Miner. Vol. II. p. 384.*



experienced makers of red lead in Derbyshire. There have been great disputes amongst philosophers, to what principle this increase of weight should be ascribed; some have attributed it to what they call the matter of fire; others are upon good grounds convinced, that it is owing to the absorption of the air itself, or of some of the principles of which the air consists. This hypothesis concerning the fixation of air during the calcination of metals, is said to have been first advanced by *John Rey*, a French physician, in 1630; *Dr. Hales* was partly of the same opinion\*; and *Dr. Pemberton* very expressly affirms, that calcined metals receive their increase of weight from the air, which, “ by acting on the inflammable

\* *Veget. Stat.*

ble substance, either in metals or other bodies, expels it from them, and unites itself (in part at least) to the remains of the body\*." The ingenious labours of Dr. *Priestley* and of M. *Lavoisier* have confirmed the conjectures and experiments of former philosophers, for they have clearly proved two points — first, that a large portion of air may be *separated* from red lead, by *reducing* it to the state of a metal;—and secondly, that a large portion of air is *absorbed* by *lead* during the calcination, by which it is reduced to the state of red lead†.

During the calcination of lead, it is certain, from what has been said, that

\* Pember. Chem. p. 245.

† Priestley's Exper. and Lavoisier's Essays, translated by Henry.

that much of its substance is dispersed into the air; this substance may indeed be seen ascending as a smoke from the surface of the lead, if the heat be so great as to make it boil; and in a less degree of heat, the vapour which ascends from it may be rendered visible, by holding over it a wet iron ladle to condense it. But at the same time that the lead loses considerably of its weight by the volatilization of part of its substance, it receives such an accession of new matter from the air, as renders the weight of the part which remains, much greater than that of the whole lead which was exposed to calcination. This accession of aërial matter may be driven off from red lead, by restoring to it the inflammable principle which was consumed during the

the calcination; but after this extraneous matter is driven off by reducing the lead, we ought not to expect that the lead, which is thus brought back to its former state, should weigh as much as it did before it was calcined; because that part of it which was volatilized and dispersed into the air cannot be recovered. And in fact, it was observed in the last Essay, that three tons of lead, when converted by calcination into litharge,\* had lost two hundred weight; this quantity, and, probably, much more than this, had been volatilized and lost, for the remaining fifty-eight hundred weight consisted partly of the earth of lead, and partly of the air which had been fixed in it during the calcination; and hence, when it was reduced, it did not give  
above

above fifty-two hundred weight. In calcining then, and reducing sixty hundred weight of lead, there is a loss of eight hundred weight : a great part of this loss is rightly referred to the volatilization of the lead, but a part also may justly enough be referred to the scoria which remains after the reduction of the litharge into lead, that operation being seldom performed so accurately as not to leave some part of the litharge unreduced. I have here spoken of the loss of weight sustained during the reduction of litharge, as if it was the same as that which red lead sustains ; there probably may be some difference between them, but the general inference is the same ; and I have been informed moreover, that there is neither increase nor decrease

crease in weight in converting litharge into red lead\*.

In making red lead in Derbyshire, the workmen mix one hundred weight of *slag* lead with about eighteen hundred weight of *ore* lead; and they are persuaded that this *slag* lead has a great effect, in accelerating the conversion of the other lead into an earth. *Tin*, when mixed with lead, very much promotes its calcination; and the *slag* lead has this pro-

\* This observation does not accord with that of the author of the Familiar Discourse concerning Mines, p. 34. — “20 hundred weight of this litharge will produce 22 hundred weight of red lead.” Another author informs us that 20 pounds of lead will, by a long calcination, give 25 pounds of ashes, and that these 25 pounds of ashes will, when reduced, give 19 pounds of lead. Lemery Cours de Chym. p. 145.

property in common with a mixture of tin and lead, that it does not, when melted, exhibit any colours on its surface : may not its properties, by which it is distinguishable from ore lead, arise from its containing zinc or tin ? We are too apt, I think, to look upon the ores of lead as containing only one metal ; since we are certain that they all contain two, namely, lead and silver ; and it may be, that they contain other metallic substances, particularly zinc and tin.

In converting a ton of lead into red lead, the workmen observe, that towards the end of the operation, a few pounds of lead are always found to remain, which cannot be changed into red lead, with the same facility with which ordinary lead is changed. When I was first informed  
of

of this circumstance, I considered it in the following manner.—Derbyshire lead, though it does not contain silver enough to render the extraction of it profitable, yet it generally contains five or six ounces in a ton: silver is not capable of being converted into an earth by the action of air and fire, when therefore a ton of lead is converted, as to its greatest part, into red lead, why may not the six ounces of silver contained in that lead be left unaltered? and may not the superior difficulty of reducing the last portion of the lead into red lead, proceed from hence, that it is much more impregnated with silver, than ordinary lead is? Under the influence of this conjecture, I procured from Derbyshire, some of the lead which remained



uncalcined in the making of red lead, and I assayed it for silver, but it did not contain more silver than many specimens of ore lead contained.

It has been remarked more than once that red lead may be *reduced* into lead, by being melted with rosin, tallow, charcoal, or any substance containing the inflammable principle. The proof of this is very easy; a few grains of red lead being scattered on a piece of red hot-charcoal, will be changed into globules of lead; or if the reader burns a common red wafer in the flame of a candle, holding a piece of white paper under it, he will see many red-hot globules falling upon the paper, and these globules he will find to be lead: this lead proceeds from  
the

the red lead with which ordinary wafers are coloured, being *reduced* into the state of a metal, by uniting itself with the inflammable principle. The best wafers are coloured with vermilion—powdered *cinnabar*\*.

Having been disappointed in the expectation of finding a large proportion of silver, in the small residue of lead remaining after the conversion of ordinary lead into red lead; and being unwilling to give up the notion, I was desirous of convincing myself that I had not been guilty of any mistake in the assay that I had made, by trying whether red lead itself did not contain silver; for if red lead contained silver, I saw no reason

to

\* Cinnabar is an ore of quicksilver; it is composed of quicksilver and sulphur; generally of 7 parts of quicksilver to 1 of sulphur.

to be surprised at the residue, before mentioned, not containing more than I found it to do. I therefore reduced a quantity of red lead into the state of a metal, by melting it with rosin; this reduced lead was carefully assayed more than once, and it always afforded a portion of silver. Hence we may conclude, that the silver contained in lead, though it be not subject to calcination during the process of making red lead, is nevertheless mixed with the calcined lead in such a comminuted state, as to escape our senses; the silver, probably, is still in the form of silver, but its particles are so indefinitely fine, that they cannot be distinguished in the mass of red lead, which contains them.

The method of making slag lead  
has

has been described before ; I assayed this kind of lead several times, and I sometimes obtained from it a globe of silver, at other times there was no appearance of silver. This difference in the result of the assays is not to be attributed to any difference in the quality of the slag lead which was assayed, for all the pieces which I tried were cut from the same lump, but to the different degrees of heat used in the operation ; when the fire was too strong, the silver, I conceive, was *volatilized*. Silver, I know, is looked upon as a *fixed* metal, and not capable of being volatilized ; and the loss of silver, when the fire is too strong, has been attributed to its not being volatilized, but absorbed by the *cupel* : I have no objection to this account :

but that the volatilization of silver on the cupel is no unwarranted conjecture, appears from hence, that in the last process of refining lead for silver at Holywell, so much of the silver is carried into the chimney of the furnace, that they have procured a silver cup from melting the sweepings.

A great quantity of lead is annually imported in the tea boxes from China; a Congo box contains about 10 pounds, and an Hyson box about 4 pounds of lead; I have frequently assayed this lead, and always found that it contained silver, but not in quantity sufficient to quit the expence of extracting it.

Pure lead is heavier than pure silver, and the purer the lead the greater is its weight; I calculated the weight

weight of a cubic foot of five different sorts of lead :

Weight of a cubic foot of

Avoir. Oz.

|                                      |       |
|--------------------------------------|-------|
| Lead from the reduction of red lead  | 11460 |
| Lead uncalcined in making red lead   | 11331 |
| Lead smelted from an ore             | 11262 |
| Lead from the slag of a cupola furn. | 11212 |
| Lead from a tea box                  | 11176 |

The experiments from which I formed this table were repeated at different times, and the mean of several trials in the respective sorts is expressed. A cubic foot of fine silver weighs 11091 ounces\*.

The following assays of the several leads here mentioned, were made by an experienced assayer in London; they are very little different from those

\* Cotes.

those which I myself had made, but I was desirous that the reader might rely upon the authority of a person versed in the particular business of assaying, rather than upon mine.

Fine silver in a pound of

|  | Grains          |
|--|-----------------|
| Lead from the reduction of red lead -  | 1 $\frac{1}{2}$ |
| Lead uncalcined in making red lead     | 1 $\frac{1}{2}$ |
| Lead smelted from an ore - - -         | 1 $\frac{3}{4}$ |
| Lead from the slag of a cupola furn. - | 1 $\frac{3}{4}$ |
| Lead from a tea box - - - - -          | 1 $\frac{3}{4}$ |

From comparing the two tables together, we see that the heaviest lead contains the least silver. I do not think, that persons interested in knowing the quantity of silver contained in any particular specimen of lead, should rest satisfied with assaying so small a portion as a pound, especially if no notice is taken of

any weight less than one fourth of a grain.

*White lead*, or *ceruse*, is lead corroded by vinegar. Thin plates of lead are rolled up in a spiral form, and placed in earthen pots containing vinegar; these pots being ranged on proper stages, and their mouths being covered in such a manner as to permit the vapour of the vinegar to escape, and at the same time to prevent any impurity from falling into them, a quantity of horse-dung is thrown in amongst them; by the heat of which, as it grows putrid, the vinegar is raised in vapour, and this vapour attaching itself to both sides of every spiral of the lead, which is so placed as not to touch the vinegar, it corrodes the lead into white scales, which being beat off  
from



from the plates, washed and ground in a mill, constitute the white lead of the shops, excepting that this is generally, even before it gets into the hands of the painters, adulterated with chalk. *Ceruse* was formerly made by the vapour of putrid urine instead of vinegar. The time when this preparation of lead was first discovered, is wholly uncertain; *Dioscorides* speaks of its being made in great perfection at *Rhodes*, *Corinth*, and *Lacedemon*, and of an inferior sort of it at *Puteoli* \*; and *Pliny* describes two ways of conducting the operation, both of which are now in use†.

The *Roman ladies* were well acquainted with the use of *ceruse* as a cosmetic: *Plautus* introduces a waiting

\* *Diosc. Lib. V. C. 103.*

† *Lib. XXXIV. S. 54.*

ing woman refusing to give her mistress either *ceruse* or *rouge*, because, forsooth, in the true spirit of a flattering Abigail, she thought her quite handsome enough without them\*. I suppose the Christian ladies in the days of *St. Jerome*, were given to this pagan custom, for the venerable father inveighs very forcibly against the

\* — non do, scita es tu quidem,  
 Nova pictura interpolare vis opus lepidissimum,  
 Non istanc ætatem oportet pigmentum ullum attingere,  
 Neque cerusam, neque melinum, neque aliam ullam offuciam.  
 Plaut. Most. Act. I.

Quid faciat in facie Christianæ purpurissus et cerusa, quorum alterum ruborem genarum, labiorumque mentitur, alterum candorem oris et colli, ignis juvenum, fomenta libidinum, impudicæ mentis indicia. Hieron. ad Iulscum.

the use of *rouge* for the lips and cheeks, and of *ceruse* for the face and neck, as incentives to lust, and indications of unchaste desires. Without presuming to explore the *arcana* of a lady's toilet, or to reveal the arts by which my fair countrywomen endeavour to improve charms naturally irresistible, I would add to the admonition of St. Jerome, a caution more likely, in these degenerate times, to be attended to — the certain ruin of the complexion, to say nothing of more serious maladies, which must ever attend the constant application of this drug. Nor is the *magistery* of *bismuth* or *Spanish white*, as it is called, much less pernicious than *ceruse*, notwithstanding its being in such repute in London, that the chemists can hardly  
pre-

prepare it fast enough to supply the demand for it\*. But if, as is most probable, they will neglect this caution, I warn them, however, to forbear the use of such washes at Harrogate, Moffat, and other places of the same kind, lest they should be in the state of the unlucky fair one, whose face, neck, and arms were suddenly despoiled of all their beauties, and changed quite black by a sulphureous water. Indeed, all phlogistic vapours, and even the sun itself, tends to give both the magistery of bismuth, and ceruse, a yellow colour: this observation may explain  
a line

\* The magistery of bismuth is made by dissolving that semimetal in aqua fortis, and precipitating the dissolved bismuth from the acid, by water.

a line in *Martial*, where a *cerused* lady is said to fear the sun\*.

Other fluids, besides the vapour of vinegar, corrode lead into a kind of ceruse. When plumbers strip the roofs of churches, or other buildings covered with lead, which has lain undisturbed for many years, they usually find that side of the lead which is contiguous to the boards, covered with a white pellicle, as thick sometimes as an half crown; this pellicle is corroded lead, and is as useful for painting, and other purposes, as the best white lead. The lead on the south side of any building is found to abound most with  
this

\* ——— *cerata timet Fabulla nimbū,*  
*Cerusta timet Sabella solem.*

this white crust; that on the north side having very little, or none at all of it. It is believed also, that lead which lies on deal boards, is not so apt to be covered with this white incrustation, as that which lies upon oak: if there be any truth in this observation, it may, perhaps, be explained from hence, that oak contains a much stronger acid than deal, and this strong acid being distilled, as it were, by the heat of the sun in summer, attaches itself to the lead, and corrodes it: or this corrosion may be the effect of the sun and air, which, by their constant action, calcine or corrode the lead; and this calcined lead not being washed off by the rain, may, in the course of a great many years, form the crust here spoken of. It might be worth while

while, in a philosophical view, to examine more minutely than has been done, the difference between old lead which has lost some of its parts by long exposure to the air, and new lead. The plumbers have assured me, that if a pig of old lead, and an equal pig of new lead, be put together into the same iron pot, and exposed to the same degree of heat, the new lead will be melted much sooner than the old lead. Another difference betwixt them, respects the quickness with which they may be reduced to a *calx*, the new lead being observed to calcine much faster than the old.

Neither ceruse, nor litharge, nor minium, have any taste; but any of these substances being boiled in distilled vinegar, which has an acid taste,

taste, will be dissolved in it; and the solution being crytallized will give one of the sweetest substances in nature, called *Saccharum Saturni*, or sugar of lead. It is this property which lead has of acquiring a sweet taste by solution in an acid, that has rendered it so serviceable to those wine merchants who, respecting their own profit more than the lives of their customers, have not scrupled to attempt recovering wines, which had turned sour, by putting into them large quantities of ceruse or litharge. I believe this adulteration is punished with death in some parts of *Germany*; and it is to be wished that it met with that punishment every where. In 1750, the farmers general in *France* being astonished at the great quantities *de vin gâté* which



were brought into *Paris*, in order to be made into vinegar, redoubled their researches to find out the cause of the great increase in that article; for near thirty thousand hogsheads had been annually brought in for a few years preceding the year 1750, whereasthe quantity annually brought in forty years before, did not exceed 1200 hogsheads. They discovered, that several wine merchants, assuming the name of vinegar merchants, bought these four wines (which were still rendered more sour by the custom of pouring into each hoghead six pints of vinegar before it was sold), and afterwards, by means of litharge, rendered them potable, and sold them as genuine wines \*.

Our

\* Exam. Chy. de Differ. Subst. par. M. Sage.  
P. 157.

Our English vintners, there is reason to fear, are not less scrupulous in the use of this poison than the French wine merchants; for it not only corrects the acidity of sour wines, but it gives a richness to meagre ones, and by this property the temptation to use it is much increased.

The reader may soon furnish himself with the means of detecting lead when dissolved in wine. Let him boil together in a pint of water, an ounce of quicklime, and half an ounce of flour of brimstone, and when the liquor, which will be of a yellow colour, is cold, let him pour it into a bottle, and corking it up, reserve it for use. A few drops of this liquor being let fall into a glass of wine or cider containing lead,

will change the whole into a colour more or less brown, according to the quantity of lead which it contains; if the wine be wholly free from lead, it will be rendered turbid by the liquor, but the colour will be rather a dirty white than a blackish brown. *Van Helmont*\* was of opinion, that *Paracelsus* made no vain boast, in saying that he could cure two hundred diseases by preparations of lead; but he does not tell us of the many hundred persons he, probably, sent to their graves by his attempt. But it is beyond my ability, and falls not within my design, to discuss either the salubrious or poisonous qualities of lead; especially as the labours

\* Adeo ut non frustra Paracelsus gloriatur solo plumbo forte ducentas morborum classes superare posse. *Helm. Op. p. 561.*

labours of Sir G. Baker\* and Dr. Percival† have so fully illustrated that subject. ,

Having accidentally heard, during the printing of this volume, that Dr. Priestley had discovered a method of reducing red lead to its metallic form, by melting it, in contact with inflammable air, by means of a burning glass, I was very desirous of having so remarkable a fact confirmed by other experiments. But being prevented by a bad state of health from venturing into an laboratory myself, I communicated my wishes and ideas to an ingenious gentleman of this university‡, who has for some years been cultivating chemistry with a pro-

\* Med. Eff. † Eff. on the Poison of Lead.

‡ Rev. Mr. Milner, A. M. Fellow of Queen's College,

a proper degree of enthusiasm, and he has succeeded in reducing red lead by means of inflammable air in the following manner. To one end of a glass tube, into the middle of which some red lead had been put, an empty bladder was tied; to the other end a bladder full of inflammable air, obtained from a solution of iron in the acid of vitriol, was fastened very close: that part of the tube, in which the red lead was principally lodged, being heated almost red hot, by being held over a small crucible full of burning charcoal, the inflammable air was pressed out of the bladder; at its first passage through the tube the red lead became brown, as if it had been mixed with some *oleaginous* particles; and by pressing the bladders alternately for a short

a short space of time, the red lead was reduced into small globules of lead; the quantity of inflammable air was sensibly diminished, a part of it having been absorbed by the red lead when it became a metal. .

Occasion was taken in another place to remark, the inflammable air, as a constituent part of combustible bodies, bore a great resemblance to phlogiston\*, and a doubt also has been expressed, whether the phlogiston of metallic substances be not an elastic inflammable fluid; this experiment, in which lead is reduced by absorbing inflammable air, tends very much to strengthen that hypothesis, and I doubt not we shall see reason to admit it without hesitation, when the subject has been more investigated;

\* Vol. II. p. 337.

investigated; at present I do not  
 know whether it has been proved  
 that the *whole* of any definite quan-  
 tity of inflammable air can be ab-  
 sorbed by a metallic earth, nor, if  
 it cannot, what the nature of the  
 remainder is: but the removal of  
 these, and other doubts, will be best  
 accomplished by the ability of him,  
 to whom we owe the first suggestion  
 of the phlogiston of metallic sub-  
 stances being an inflammable air.

END OF VOL. III.











